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PREFACE.

A SPECIAL course of three lectures on Suction Gas Plants was recently given at the East London College. This course was attended by members of the Institution of Marine Engineers, the Association of Engineers-in-Charge, the Junior Institution of Engineers, and students of this and other Colleges. It is at the request of many of the engineers who attended the lectures that they are now published.

A great amount of correspondence followed the delivery of the lectures, and the discussion which took place at the close of the third lecture was especially interesting. This correspondence was requested, as it was desired to know whether the subject had been treated in a fashion simple enough to be understood easily, and advanced enough to be of service to engineers in practical work. It was exceedingly kind of many of the correspondents to take such a great deal of trouble, and to make many clear suggestions which have been incorporated in this book.

It would not have been possible to present these lectures in their present form but for the services of my friend Mr E. A. Allcutt, B.Sc., of the University of Birmingham. Owing to the pressure of other work, the lecturer could give only suggestions and notes concerning the treatment of the points raised in the correspondence. Mr Allcutt has dovetailed these inquiries and the lecturer's replies to them into the text of the lectures.

The illustrations have been especially prepared from drawings supplied by various firms. Every endeavour has been made to keep the appearance of the illustrations different from those used in trade catalogues.

The lecturer's thanks are given to the following firms who supplied him with much useful information, viz. Messrs Campbell, Tangye, Fielding & Platt, Crossley, Newton Bros., the National Gas Engine Co. (especially to Mr Robson), the Hornsby Producer Co., the Power Gas Corporation, Messrs Dowson & Grice. Many of these firms supplied lantern slides and copyright information, and afforded opportunities for personal discussion on points raised. The Editors of *Engineering* and of *Cassier's Magazine* are cordially thanked for their permission to use information contained in their valuable journals.

Professor D. A. Low kindly acted as chairman during the lectures, and the discussion which followed. He also made many suggestions concerning the arrangement of this book, and his experience in such matters has been of great value. This opportunity is taken to thank him sincerely for his help and advice. Mr Tookey and other gentlemen who took part in the discussion are also warmly thanked for the great interest which they took in the matter.

If this book were worthy of a dedication, that should be given to the lecturer's *Alma Mater*, the University of Birmingham, from which seat of learning he obtained most valuable views upon the problems, technical and general, which face every engineer during his work.

C. A. SMITH.

LONDON, *December* 1908.

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SUCTION GAS PLANTS.

LECTURE I.

INTRODUCTORY MATTER.

Introduction.—For over a century the steam engine was invariably used for the purposes of converting the heat contained in coal into mechanical energy, but there are many who believe that, just as the last century was connected with the growth and development of steam engines, which culminated in the triumph of the steam turbine, so the present century will always be connected with the enormous growth in the applications of internal-combustion engines. Whether any of us now living will ever see the triumph of the gas turbine is a matter entirely for speculation; theoretical experts have pointed out reasons why such a machine would be the most efficient method yet thought out for converting the heat of coal into mechanical energy, and practical experimentalists have shown equally clearly the difficulties which must be overcome before such hopes can be realised. Our intention is rather to deal with the present than with the future, although the work of the pioneers in any branch of engineering must always prove deeply interesting.

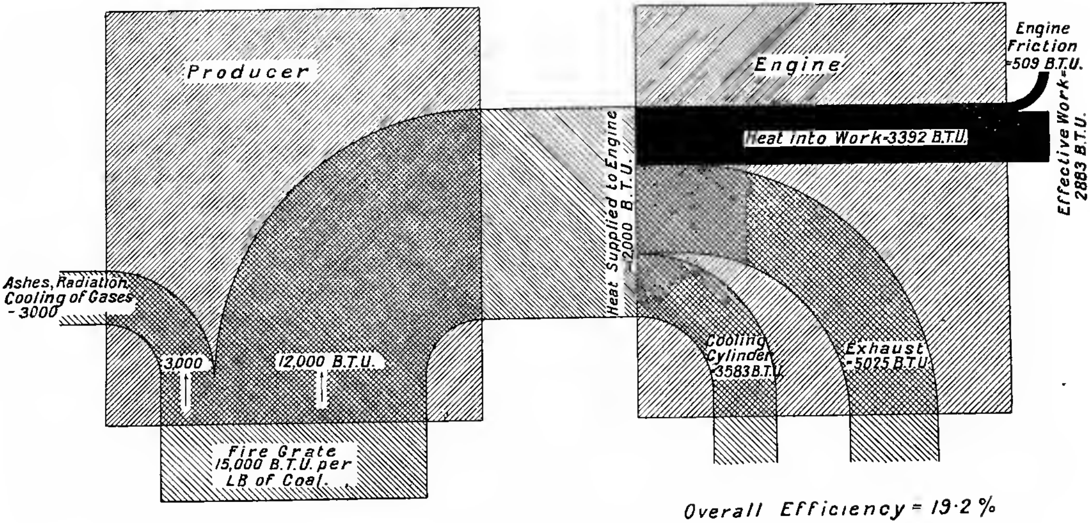
It is impossible to deal, in the course of these lectures, with anything but suction gas plants. Although it may be necessary to refer generally to pressure plants, it will be understood that the intention is to discuss the details of suction gas plants only. At the same time, it is only fair to point out that, but for the perseverance of those firms who have so successfully developed gas engines, we should never have had the suction gas plant.

We may say that the suction gas plant consists of three essential parts:—First, the gas-producer necessary to convert the coal into a gaseous state; in the petroleum engine the carburettor corresponds to this gas-producer. Secondly, there is the engine cylinder, in which the heat of the gas is utilised and work is done on the piston of the engine. Thirdly, there is the mechanism which transmits the work done in the piston to the driving shaft, where it can perform mechanical work. We intend to deal in detail with the first part only.

Comparison between Steam and Gas Power.—Among the many strong arguments which can be brought forward in support of gas engines and producers, there is one which will appeal to the patriotic and to the man who wishes to husband the mineral resources which form a considerable portion of the wealth of this country. When coal is burnt in boilers for supplying the steam used in small-power engines, at least nine-tenths of the heat energy which Nature has so kindly stored up for us is utterly wasted. The thermal efficiency of the best steam engine working under the most modern conditions is about 17 per cent., which means that 83 per cent. of the available heat in the steam is lost in the engine. A comparison of the losses in a suction gas plant with those in a steam plant is shown diagramatically in figs. 1 and 2. We start in the latter case with coal having a calorific value of 15,000 B.T.U. per lb. Tracing the heat in one pound of coal through the plant we find that 4200 B.T.U. are lost in the boiler, leaving 10,800 B.T.U. to enter the engine (that is, if there are no steam pipe losses). Of these 10,800 B.T.U. we lose 9396 in engine losses and get only 1404 B.T.U. as work in the engine cylinder. Then, again, 100 B.T.U. are lost in engine friction, so that the effective work only amounts to 1304 B.T.U. per lb. of coal, or an overall efficiency of 8·7 per cent.

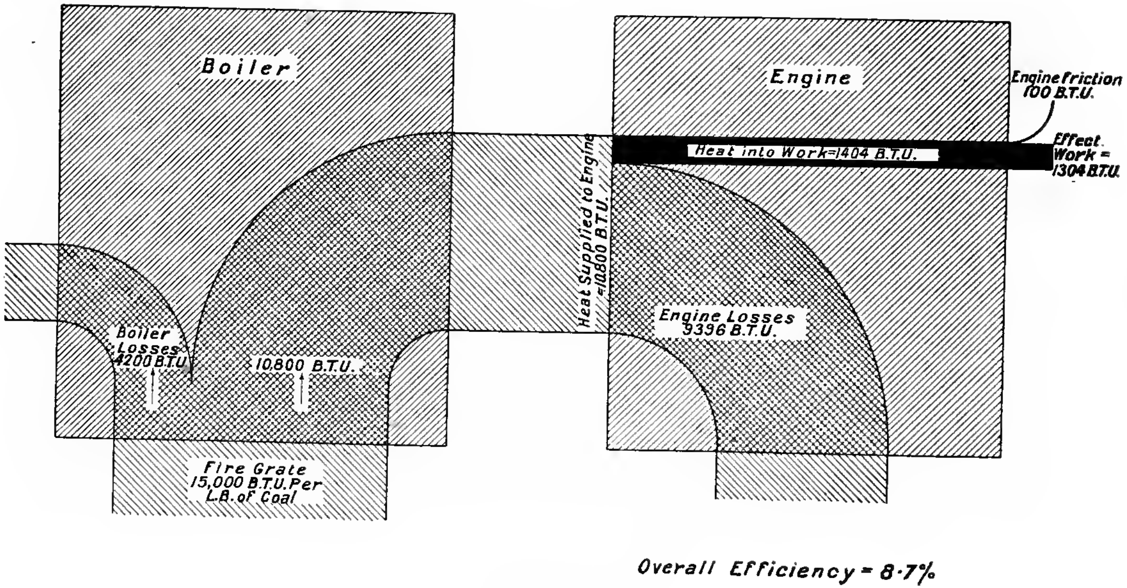
Taking the same quality of coal, we will trace the heat from 1 lb. through a suction gas plant. We lose 3000 B.T.U. in the producer plant through ashes, radiation, and cooling of gases, leaving 12,000 to enter the engine. Of these, 3583 B.T.U. are carried off by the cooling water, and 5025 are rejected with the exhaust, leaving 3392 B.T.U. as work in the cylinder. The mechanical efficiency of the gas engine being less than that of the steam engine, we will deduct 509 B.T.U. for engine friction. The net work is then equivalent to 2883 B.T.U. per lb. of coal, or an overall efficiency of 19·2 per cent., more than twice that of the steam plant. Taken as a whole, the efficiency of the best steam plant, furnace and boiler, engine and mechanism, is only about 12 per cent., and it is reckoned by most authorities that an average of between 5 and 6 per cent. is probably the most exact value. But if we compare such figures with those obtainable with the gas producer and gas engine we find everything in favour of the latter. The efficiency of the suction gas producer is high, and may be safely reckoned at 85 per cent., and has been stated by good authority to be as high as 90 per cent. (of course, it is the overall efficiency of the plant which must be considered), and the thermal efficiency of the gas engine can be reckoned at 30 per cent. It is worth noticing, however, that we must look for greater improvements in the future from the engines rather than from the producers. At the same time, finality has by no means been reached yet in the latter. It will be in the perfection of details in construction and arrangements for increased durability (at present very good) that we may see the energies of manufacturers concentrated.

History and Development of the Suction Plant.—England, the cradle of the steam engine and steam turbine, was also the first country in which a really efficient gas producer was introduced. We are rather apt to forget, however, in a lifetime, the debt we owe to the pioneers. I would therefore embrace this opportunity to emphasise the work of Mr J. E. Dowson of London, for it is largely due to his determined efforts that we find producer plants becoming popular. Sir William Siemens brought the first producer plant into this country from Germany, but that does not minimise at all the work of Mr Dowson. The early producers were all pressure plants. Mr Benier may claim to have made the first step towards a suction gas producer in 1894, when he designed a producer to make its own steam, instead of using a separate boiler, as do pressure plants, thus automatically controlling the supply of steam to the producer. For should steam


Producer
Ashes, Radiation, Cooling of Gases - 3000
3,000
12,000 B.T.U.
Fire Grate 15,000 B.T.U. per LB of Coal.
Heat Supplied to Engine 12,000 B.T.U.
Engine
Engine Friction =509 B.T.U.
Heat into Work-3392 B.T.U.
Effective Work=2883 B.T.U.
Cooling Cylinder -3583 B.T.U.
Exhaust -5025 B.T.U.
Overall Efficiency = 19·2 %

SUCTION GAS PLANT.

FIG. 1.—Diagram of Heat Losses per lb. of Coal.


Boiler
Engine
Engine Friction 100 B.T.U.
Effect. Work = 1304 B.T.U.
Heat into Work=1404 B.T.U.
Heat Supplied to Engine =10800 B.T.U.
Engine Losses 9396 B.T.U.
Boiler Losses 4200 B.T.U.
10,800 B.T.U.
Fire Grate 15,000 B.T.U. Per L.B. of Coal
Overall Efficiency = 8·7%

STEAM PLANT.

FIG. 2.—Diagram of Heat Losses per lb. of Coal.

be raised in excess of the demand on the plant, the temperature of the producer falls, thus speedily reducing the supply of steam to that required by the load.

About the same time Messrs Körting Bros. introduced a further improvement by dispensing with the suction pump, and allowing the suction stroke of the engine to provide the necessary vacuum to draw the gas through the plant.

The credit of being the first makers of suction gas producers in this country is claimed for Messrs Crossley (1901). Mr W. A. Tookey informs me, however, that the first plant was designed by Dr Bowman, and manufactured by the Dynamic Gas Company of Manchester.

So rapid has been the advance of this type of plant into popular favour, that at the present moment there are actually twenty-five British designs of suction gas plants upon the market, and as many as twenty firms are engaged in the business of manufacturing. In order that we may have some grasp of the figures, let me say that Mr Dowson informs me that his firm have already supplied 50,000 B.H.P. suction gas plants. It can safely be taken that at the present moment some 300 new plants are being produced per annum, and the astonishing thing is that this has all happened during the last five or six years. Do not mistake me. There are, of course, pressure producer gas plants, and you are possibly so familiar with Mr Dowson's name, that you will imagine he has been making these suction gas plants for a much longer time than has actually been the case. He was for a long time, and still is, associated with the manufacture of pressure plants.

Reactions of Gas Producer.—It is now necessary to give a brief outline of the chemical actions which take place within the producer. It is a well-known fact that when air is passed over red-hot carbon, in quantity, we obtain the combustible gas carbon monoxide (CO). In reality, the oxygen of the air first combines with the carbon to form carbon dioxide (CO_2), but this, on passing over more of the red-hot fuel, is reduced to carbon monoxide (CO). This action is an exothermic one: that is, heat is given out to the extent of 8900 B.T.U. for every pound of carbon consumed. The nitrogen of the air, of course, remains unchanged and dilutes the

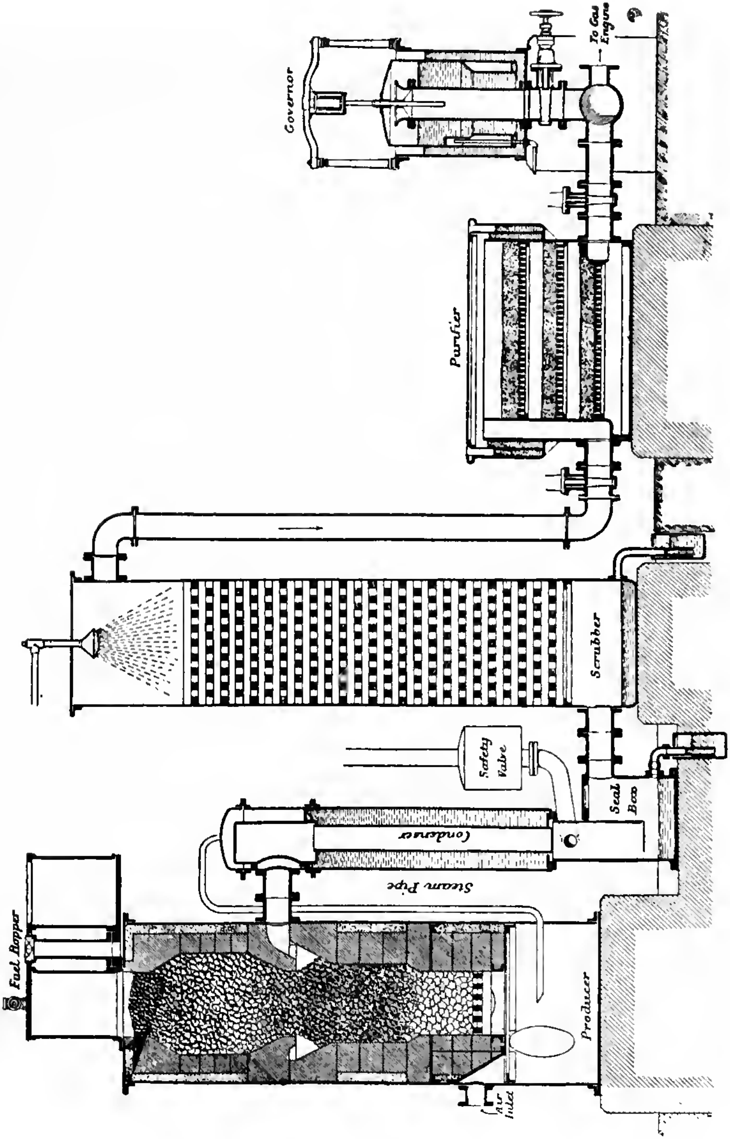


FIG. 3.—The First Practical Suction Gas Plant shown by H. Cerdes to the Society of German Mechanical Engineers.

gas, thus lowering its calorific value. The "air gas" thus obtained would have a heating value of something like 120 B.T.U. per cubic foot.

Since heat is being given out at the rate of 8900 B.T.U. for every pound of carbon consumed, the temperature of a producer working on air blast alone would be very high, and serious practical difficulties would thus be introduced. To avoid these, the usual practice is to add to the air a certain quantity of steam.

Now, steam reacts with carbon (or coal) on its own account, in the following way :—

$$H_2O + C = H_2 + CO,$$

the products of the reaction being carbon monoxide and hydrogen. Both of these gases are combustible, and so the calorific value of "water gas" is high, being about 350 B.T.U. per cubic foot. The action itself, moreover, is endothermic: that is, it absorbs heat to the extent of 4366 B.T.U. for every pound of coal used. This, of course, has the desired effect of reducing the temperature of the producer to a reasonable and workable value.

An ideal composition for the mixture of air and water gas thus produced would be—

$CO = 39{\cdot}9$ per cent., $H = 17{\cdot}0$ per cent.
Total combustible gases, 56·9 per cent.
$N = 43{\cdot}1$ per cent.

The theoretical calorific value of this mixture of gases is 195·6 B.T.U. per cubic foot. In practice, however, the composition of suction gas is something like the following :—

$CO_2 = 7{\cdot}2$ per cent. $CO = 18{\cdot}6$ per cent. $CH_4 = 1{\cdot}6$ per cent.
$H = 17{\cdot}6$,, $N = 54{\cdot}4$,, $O = {\cdot}6$,,

The calorific value of this sample would be about 140 B.T.U. per cubic foot. The small percentage of marsh gas (CH_4) present comes from the fuel, and its quantity is dependent on the kind of coal used in the producer.

But the above are not the only reactions taking place inside the producer; for if it were so, the composition of the resulting gas would approximate much nearer to the theoretical.

In practice the carbon dioxide formed by the interaction of air and carbon is not completely reduced to carbon monoxide. It thus remains to dilute the gas. A greater quantity of heat is thus liberated, making the use of a larger quantity of steam necessary to keep down the temperature to a reasonable value. With excess of steam we get the following reaction:—

$$C + 2H_2O = CO_2 + 2H_2,$$

thus increasing the percentages of CO_2 and hydrogen and decreasing the heating value of the gas. For the action $H_2O + C = CO + H_2$ a high temperature is required, and under such conditions little CO_2 is produced. But when working with a low temperature the reversible reaction $CO_2 + C = 2CO$ acts in such a way that a balance takes place when a higher percentage of CO_2 is present than when a high temperature is employed. The difference between the theoretical and practical results obtained in a suction plant is due, first, to the fact that the fuel used is not pure carbon, but contains volatile constituents which are given off and which, if fixed, tend to enrich the gas, but if not fixed are lost in the scrubber. Secondly, a considerable quantity of heat is lost in the process of conversion of the fuel to gas, so that either the yield of gas per lb. of fuel is less, or its heating value is diminished. Thirdly, a good deal of heat is carried off by the gas and lost in the cleaning apparatus. Lastly, the reactions which actually obtain are not in accordance with those theoretically assumed; consequently there is a drop in the efficiency of the plant. The third source of loss is, in practice, partially neutralised by utilising some of the sensible heat of the gases for the purpose of raising steam in the evaporator, and also in some cases for pre-heating the air supply.

It is not intended to deal fully with the chemical calculations necessary for thoroughly understanding the production of suction gas producers. They are somewhat complex, and, after all, very much the same whatever the type of gas producer. It is absolutely necessary to master them in order to understand the directions in which progress may be made, but I feel that our object is rather to understand what we now have, than to attempt to foreshadow what we may get.

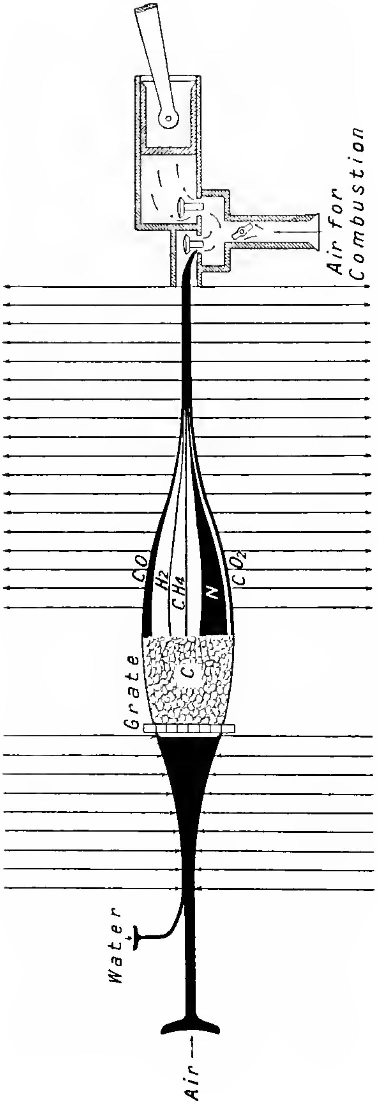


FIG. 4.—Diagram showing Change in Volume and the Reactions of Gases.

Dalby's Diagrams.—Perhaps the most useful object served by the Royal Agricultural Society of Great Britain was the competition of suction gas plants at Derby. Captain Sankey and Professor Dalby were the two judges. The latter read a most excellent paper for the British Association at York, and by means of some clever diagrams he showed clearly how the heat problem of suction gas producers may be brought to mind. In the first diagram the producer is considered to be stretched out in a straight line, the variations in the volume occupied by the gas being represented by the different widths of the diagram (fig. 4). Air and water are drawn into the producer on the suction stroke of the engine, but in order to fit them for work in the producer, the air must be heated and the water vaporised. To carry this out, heat must be supplied. This influx of heat is represented by the arrows pointing inwards. The resulting gas produced is represented in composition approximately by the black

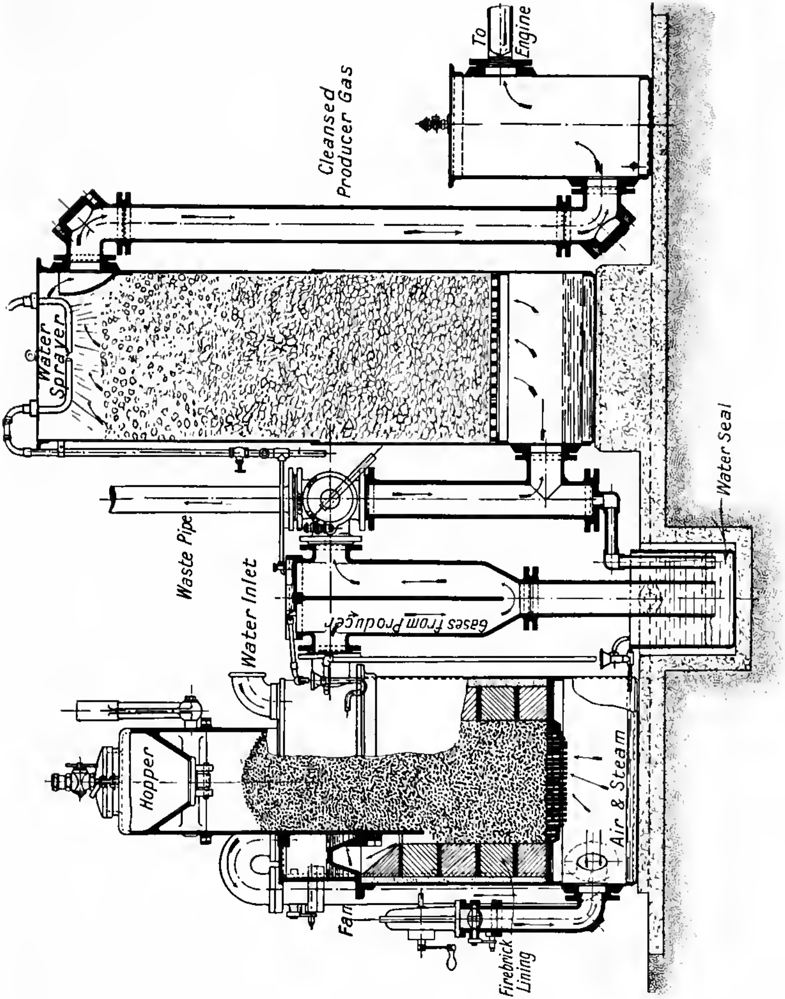


FIG. 5.—Path of the Gases passing through the Producer Plant.

lines of various thickness. But the gas at this stage is very hot, and therefore its density is small. In order that the weight of the charge in the engine cylinder should be as great as possible, the gas must be cooled, and consequently heat abstracted from it, as represented by the arrows pointing outwards.

And so as we pass on in the diagram to the gas pipe and the scrubber, we see that, owing to the cooling influence, the volume of a pound of gas is reduced greatly, and now, to follow it finally into the engine cylinder, we see that the suction stroke of the engine cylinder draws in not only gas from the producer, but also all the air that is required to make it explosive, which comes through the air pipe and throttle valve. You will remember that it is only at one stroke of the Otto cycle that the gas is sucked in to the engine cylinder, and that three strokes are used up in expanding it and cleaning the engine cylinder. It is easy enough to understand the Otto cycle, but it is hard to fully appreciate the fact that owing to the suction of the gas engine these operations can go on not only cycle after cycle, but minute after minute, hour after hour, and day after day.

It should be noticed that at the first part of the diagram heat is taken in, and at the last part of the diagram it is expelled. It is, therefore, clear that if the heat which is expelled in the latter part of the diagram can be introduced in the boiler part, there will be a great saving, and the apparatus will become regenerative.

The efficiency of the various forms of producers, therefore, must depend on the degree of perfectness with which the heat abstracted in the latter portion of the action is transferred to that part of the producer where it is required. This aimed-for result has been more or less realised in many devices. In the second diagram the incoming air and water take up the heat from the hot fuel and gases by radiation. This transference of heat is represented by the band representing steam and air being wrapped round the producer. It should be stated that at this stage of the proceedings, for every pound of carbon we have 4½ lbs. of air and about 0·84 lb. of water. Now, the above chemical reactions take place, and the air and the absorbed moisture become transformed, after having been passed through the fire. We now have a gas which contains roughly 29 lbs. of carbon monoxide, 1½ lbs. of hydrogen, ½ lb. of methane, 57 lbs. of nitrogen, and 12 lbs. of carbon dioxide in every 100 lbs. of gas. But owing to the high temperature, the volume of the gas per pound at this stage is very high, and consequently if we take it direct to the engine cylinder, we should require a very large cylinder indeed to do the work as compared with that necessary if we cool the gas down. The gas is therefore

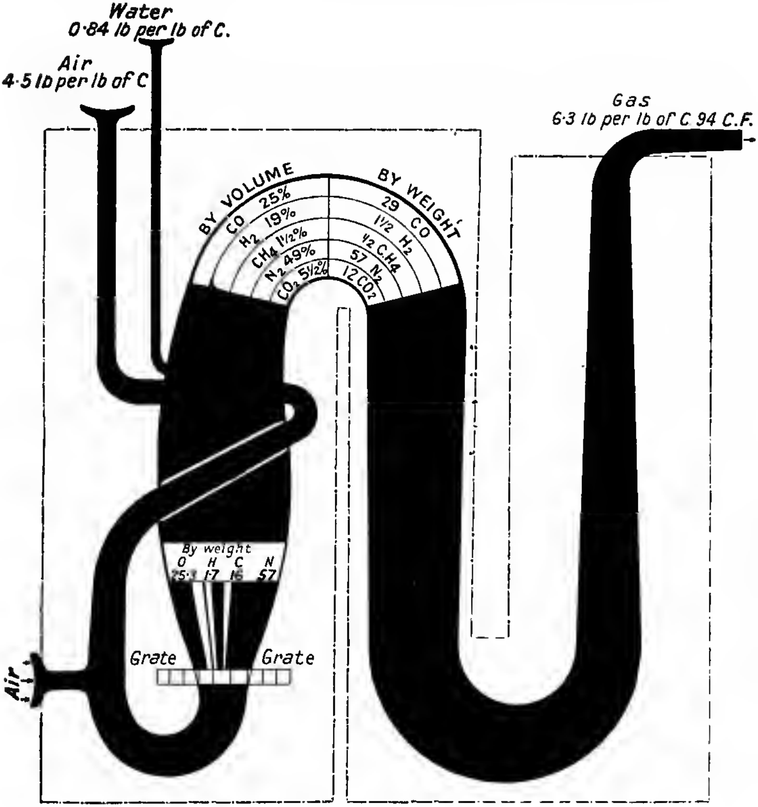


Fig. 6.—Diagram showing Volume and Weight of Gases passing through the Producer.

passed up the cooling and cleaning tower, generally called the "Scrubber."

It will be noticed that at present the heat abstracted from the gases in the scrubber is not made use of. There is also an enormous waste of heat in exhaust gases and water of the engine, and it would appear that we may expect some improvements from the regenerative system in this direction. The difficulty is to make sure that the plant is not too complicated. To find out how far we may go in this direction, we will now consider the practical details of a suction plant, and endeavour to show the principles of design that are most conducive to economical and successful working.

DETAILS OF CONSTRUCTION.

Let us take a typical suction gas plant, and find out what it consists of. The diagram (fig. 7) shows a general arrangement of a typical plant. The engine can be seen, and next to it are the scrubbers, then the steam generator, and then the producer. Now let us take the cycle of operations. First of all, the engine takes in its charge of gas from the expansion box, which is directly connected with the top of the scrubber. This scrubber in its turn is supplied with gas from the outlet pipe, which pipe connects the producer and scrubber together. And this outlet pipe is so connected that it may draw off from the producer the gas which is made by means of partially burning the fuel. Now, it is necessary that the steam should be mixed with the air and passed into the furnace. This will keep down the temperature of the latter, otherwise there might be a danger of burning out the fire-bars and cracking the body of the generator.

We thus have the vaporiser, or miniature boiler, which supplies steam for this purpose, and also for that of enriching the gas produced. This, as we have seen, is usually contained within the producer or generator.

What is the Suction Gas Producer?

It is clearly our first duty to thoroughly answer the above question before we attempt to discuss the details of the working

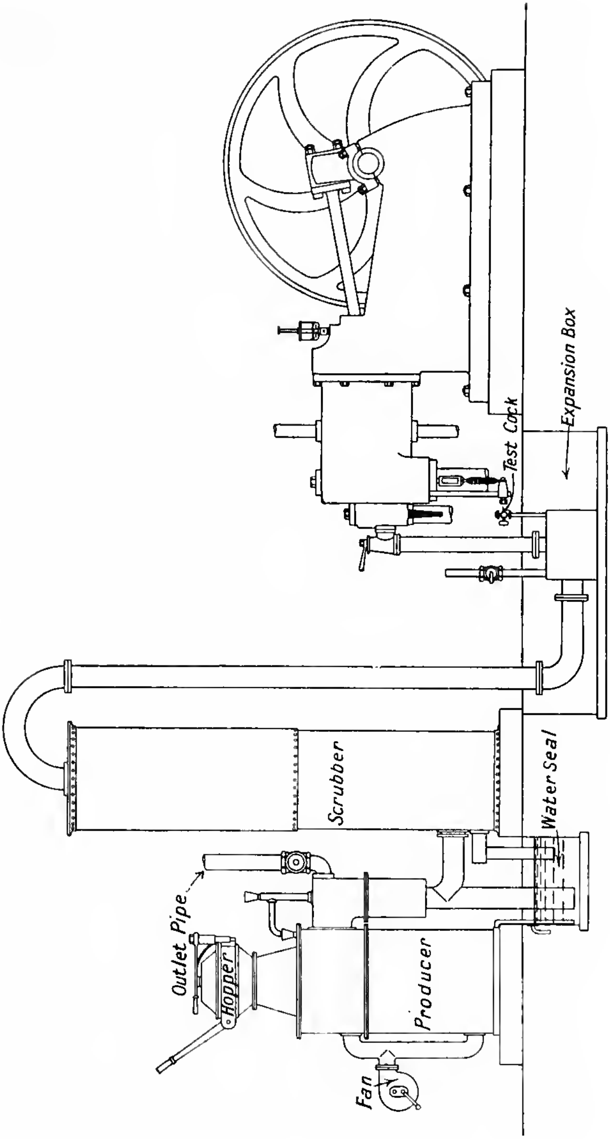


Fig. 7.—General Arrangement of Suction Gas Plant.

of producers. In order to have clear ideas, therefore, on the matter, we will see at once of what parts a suction gas producer consists.

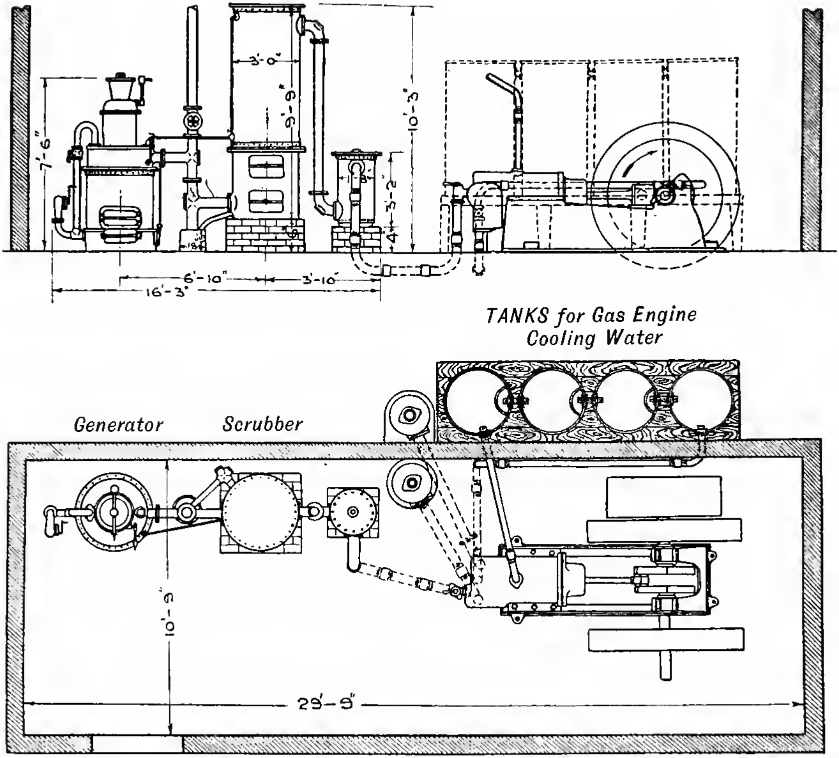


Fig. 8.—General Arrangement of a Typical Suction Plant. (Space occupied by a 60 B.H.P. Plant.)

There are essentially four parts:—

(1) A furnace, } the two combined forming the generator.
(2) A vaporiser; }
(3) A scrubber;
(4) An expansion box.

THE GENERATOR.

The generator itself may be said to consist of four parts. There is the furnace, which, of course, includes fire-grate; the vaporiser; the passages between the vaporiser and the ashpit; and lastly, the means of exit for the gas from the furnace to the scrubber.

The Furnace.—In the lower part of the furnace the fuel is burnt. There it is that carbon dioxide (CO_2) is formed, and here it is that the water vapour is broken up into hydrogen and oxygen. Air and water vapour are both drawn in from the underside of the grate by the suction of the engine. Thus it is clear that the amount of air and water vapour is automatically drawn in and regulated by the engine, and that no gas is generated from the furnace unless such air and water vapour is drawn in. The object of supplying water vapour is to provide hydrogen gas and more oxygen than is given by the air. The result of this excess supply of oxygen is that *carbon monoxide* is formed (CO). When the producer gas leaves the furnace it contains, of course, the constituents of the air and water vapour supplied, together with the carbon from the fuel. In other words, we have, entering the producer through the grate, air (consisting for practical purposes of oxygen and nitrogen) and water vapour (consisting of hydrogen and oxygen). Leaving the producer, we have hydrogen and carbon monoxide (of great use in the gas engine), some little carbon dioxide, and the nitrogen supplied with the air.

The temperature of the furnace varies. There is a zone, fairly near to the grate at which carbon monoxide (CO) is formed. In the lower layers of the fuel CO_2 (carbon dioxide) is formed from the air and carbon, but higher up this is reduced to CO by the red-hot fuel. At this point it is estimated that the temperature of the furnace is 1800° C. (3200° F.). The gases actually leave the furnace at a reduced temperature—probably on an average at somewhere about 1600° C. (2900° F.).

The combustible gases leaving the producer are hydrogen (H_2), carbon monoxide (CO), and methane (CH_4). By weight these are for anthracite coal at full load, roughly in the ratio 2 : 30 : 1.

The incombustible gases leaving the producer consist of carbon dioxide (CO_2), nitrogen (N_2), and oxygen (O_2). By weight they are for anthracite coal at full load, roughly in the ratio of 20 : 110 : 1.

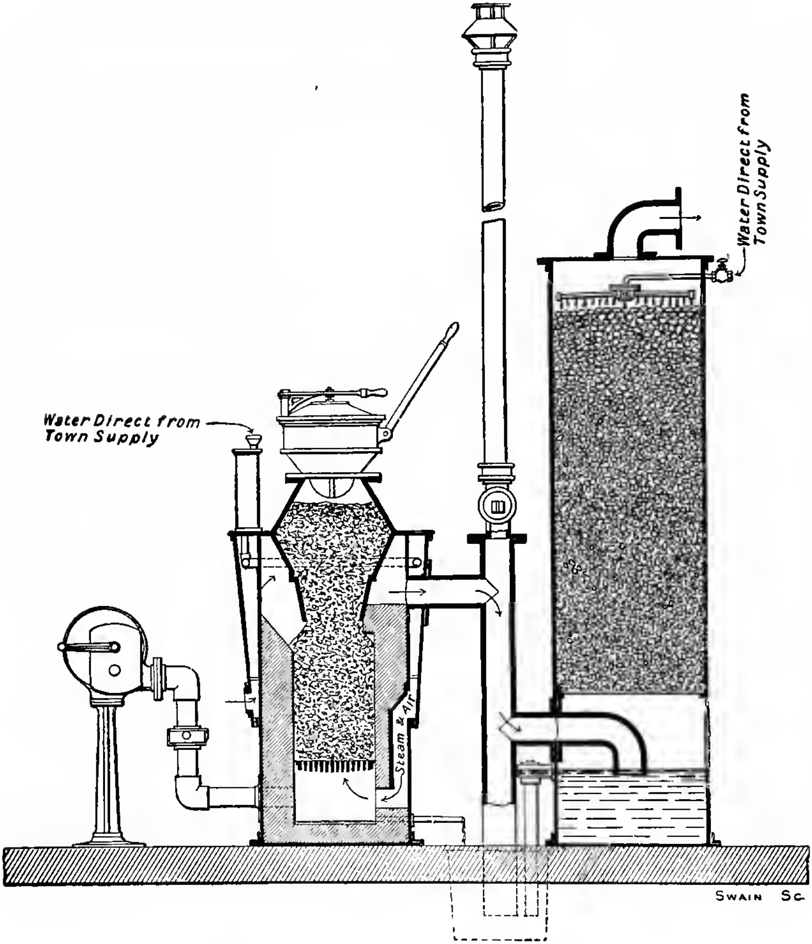


Fig. 9.—Sectional View of a Suction Plant.

By weight there are from three to four times as much incombustible gases leaving the producer as combustible gases. In this respect suction gas compares unfavourably with coal gas, and because of this fact a gas engine working on suction gas will develop less power at full load than when the engine works on coal gas.

It is, however, possible to adjust the gas engine valves so that the engine will give better results on producer gas than at first sight looks probable.

The furnace itself is very much the same in all the producers on the market. Different shapes and arrangements of the firebrick lining are to be noticed, and great ingenuity has been displayed in altering the details of the grate. In his paper for the British Association in 1906 Professor Dalby says:—

"At the present time there does not appear to be a definite relation between the proportions of the furnace of the producer and the power to be produced. The incandescent part of the fuel occupies the vertical space between the level of the grate and the bottom of the inverted cone which guides the fuel down from the hopper to the fire, and the height of this space, which is the thickness of incandescent fuel through which the air and steam are drawn, is about 2 ft. in the case of producers designed for engines of from 15 to 20 H.P. The area of the cross-section of the furnace averages about 0·065 to 0·075 sq. ft. per brake H.P. The capacity of the furnace, reckoned as the cubic contents of the space between the fire-bars and the bottom of the distributing and distilling cone, is 2·37 cubic ft. in the case of the 20-H.P. producer of the National Company. In the Crossley design the capacity is 1·58 cubic ft. for 15 brake H.P. These figures reduce to 0·118 cubic ft. and 0·105 cubic ft. per brake H.P., respectively. The diameter of the furnace in the 'National' design is 15½ in. for a 20-H.P. furnace, and in the Crossley design 12 in. for a 15-H.P. furnace, giving actual areas of 1·31 sq. ft. and 0·785 sq. ft. respectively. These figures correspond to furnace areas of 0·065 and 0·075 sq. ft. per B.H.P. The depth of the fire in the case of the 'National' engine is 1 ft. 10 in., and in the case of the Crossley producer it is 2 ft."

Experience and experiments have alike shown that, as a general

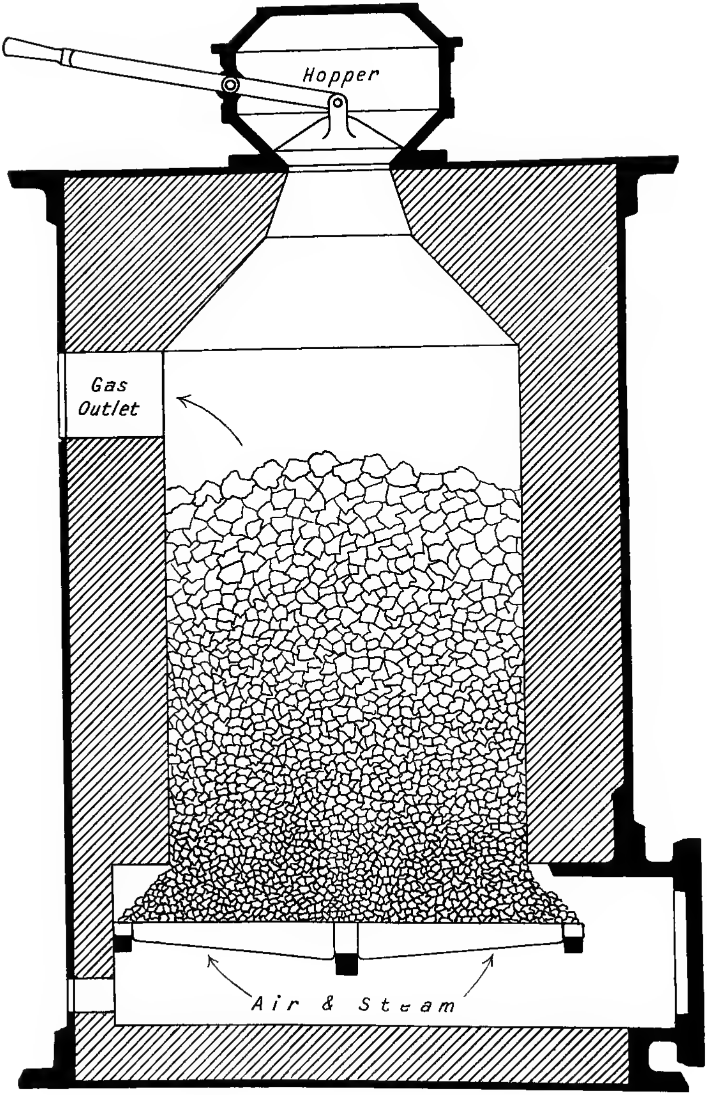


Fig. 10.—Elementary Form of Producer.

rule, the higher the velocity with which the air passes through the heated carbon, the greater is the proportion of carbon dioxide produced. That is why the area of the furnace for a given H.P. producer is considerably larger now than was at first the case. A producer is unlike a boiler, inasmuch that, under working conditions, it is almost impossible to clear out the clinkering ash without drawing the fire and emptying the whole producer. Some of this clinkering ash can, it is true, be removed when the producer is at work if there are arrangements made for cleaning doors and poking holes. This, however, requires considerable skill on the part of the attendant, and the usual cautiousness of the engineer leads him to prefer a rather larger furnace than have any trouble with his clinker. The fuel used, of course, affects the question. There is more clinkering ash in Scotch anthracite than in Welsh anthracite. Consequently, if it is intended to use gas coke or Scotch anthracite, a larger generator is required. The maker has been applied to for standard sizes all over the country, and now has experience of local fuel. He therefore usually and wisely designs for the worst and not the best conditions under which the producer is likely to be used. From the report on the trials of suction gas plants at Derby, so admirably compiled by Captain H. Riall Sankey, it will be seen that the leading makers of these plants allow about 8 sq. in. furnace area per B.H.P. for plants of about 100 B.H.P. Beyond this the proportion may be reduced somewhat, but should not go below 7 sq. in. per B.H.P.

THE HOPPER. — The furnace or generator contains another important portion, namely, the hopper used for feeding the fuel into the furnace (fig. 10). Here we have considerable diversity in the design of valves required for connecting the hopper with the furnace and with the outside. But the great point to be remembered is that all the air which goes into the producer must come in through the fire-bars, and must not come in with the fuel through the hopper. It is essential that the depth of the fuel in the furnace should remain fairly constant. It would seem to be an advantage if some automatic arrangement could be devised so that the fuel from the hopper could drop as required to keep the level of the furnace proper always constant. It would clearly be a somewhat complicated matter to arrange for this owing to the varying load on the engine, and up to the present there are only about five or six designs in which an automatic feeder is used, the general opinion being that it is unnecessary and would make the plant needlessly complicated. The general tendency of the various makers is to simplify their plants as much as possible, since the type of attendant usually in charge of this is not, as a rule, very skilled. It is not, moreover, a great deal to ask of the attendant to pull a lever across and back again, about every two hours or so, and it also serves to remind him that the plant may require more fuel in the hopper.

The Ashpit is usually closed, being formed simply by the continuation of the producer shell below the grate. In most cases horizontal grate-bars are used, but in some designs the fuel simply rests upon a heap of ashes and clinkers at the bottom of the producer. In the latter case, the shell is usually open at the bottom, the lower edges being supported in a water seal. The ashes then fall into the water, disintegrate, and are raked out, usually as a fine mud. The fuel, being deprived of its support, then sinks down, fresh coal being introduced at the hopper. In some cases the fuel merely rests on a firebrick plate, placed a little below the bottom of the producer. The air enters by the space thus formed, and the steam is also introduced at the same point. As the ashes gradually accumulate on this plate they are removed, and the fuel slowly falls towards the plate. See pp. 90, 91, figs. 25 and 26.

Most of the producers made in England have fire-grates, although they have been made on the Continent without any such fire-grates, and the fuel, as we have seen, is allowed simply to rest on the bottom of the ashpit. It is usual in English producers employing fire-grates to leave a ledge, which is annular, about one-third diameter of the producer round the edge of the fire grate, so that any clinker which forms can be poked on to this ledge.

Trouble is experienced at times with the fire-bars, which become burnt. It will usually be found that the cause of this trouble is insufficient steam supply. On the Continent, as stated above, there are no fire-bars, but an inferior quality of coal is used in the producers. It is probable that as the cheaper coals come to be used in this country, the designers will revert to a form in which fire-bars are eliminated. That is to say, when bituminous or slack coal is used, we may see such a tendency.

Try as we will it is almost impossible to make an efficient piece of engineering apparatus for generating power, fool proof. The suction gas makers have, during the short time at their disposal, made really heroic efforts to do so. But in some cases trouble comes. It is usually due to the peculiar conditions under which the plant works or the peculiar methods employed by those who are unable to make it operate.

Some makers fit a rotary or revolving grate to their producers. This consists, in one case, of a circular plate upon which the fire rests, bolted to an iron casting, and having teeth on its under side. These gear into a pinion which can be rotated by an outside handle. The flat plate on the top is renewable when required. See p. 104, fig. 32.

It is a question whether movable grates offer sufficient advantages to compensate for their large initial cost and expensive upkeep. The ordinary type of bars is much less expensive, and can be replaced without difficulty.

It is an important matter to keep all parts which are near the fire, and consequently subjected to excessive wear, as simple as possible, so that they can be replaced with little difficulty and expense.

Unnecessarily large fire-doors are fitted by many makers to their producers. It is true that large fire-doors offer facilities in the matter of clearing out the fire, but this solitary advantage is more than counterbalanced by the disadvantages attending their use. They cannot be opened while the plant is running, as much of the fire would fall out, and also leakage is more likely to take place than with small doors, with a consequent loss in efficiency. A much more satisfactory plan would be to fit three doors, just large enough to admit the clinkering tool, provided with peep-holes through which the state of the fire could be observed. With such doors runs continuing over long periods could be carried out.

The Construction of the Generator.

The great difference in the design of producer gas plants is to be found in the details of the generator. In general, such plants are very much alike. They do not vary, for example, in the way ordinary steam boilers do. There is no external difference as with water-tube and cylindrical boilers.

There are two main divisions; there are generators which are made of cast iron, and those made of wrought iron. It was at first considered doubtful as to whether it would be expedient to use cast iron, because of the high temperatures obtained. The arguments in its favour are that there is no corrosion and the joints can be machined. So far as convenience of construction goes, it appears that up to 100 B.H.P. the cast-iron producer is quite suitable. Indeed, several of the leading makers (Messrs Crossley Bros., the National Gas Engine Co., Messrs Tangye, Ltd.), use cast iron plants, except for those which are more than 100 B.H.P.; then they are built up of wrought iron plates which are riveted together. It is expedient, however, to have the ashpit and vaporiser of cast iron in all plants, as these are most liable to corrosion.

The interior lining of the producer is made of refractory clay, preferably of the best quality. To facilitate repairs, the lining should be made of pieces held together by a refractory cement, the inner surface being coated to form a continuous stone lining. It is advisable to place between the lining and the outer shell a layer of some material which is a bad conductor of heat, such as sand or asbestos (*vide* Crossley producer).

In many producers it will be noticed that the charging hopper is continued as a kind of bell below the gas outlet. In the Crossley and some other producers, indeed, it forms part of the vaporiser. The object of this bell is to prevent the gases from the raw coal passing directly away to the outlet, as these contain most of the volatile hydrocarbons, and tar, from the coal. The presence of this bell forces them to take first a downward direction and so pass through the hotter parts of the fire, when these hydrocarbons are split up and become fixed gases.

In the early days of these plants great inconvenience arose from good joints not being made. It will be understood that as the plant works on the suction gas principle it is below atmospheric pressure, and the air will therefore leak into it. The unfortunate part of it is, that if this air does leak in, it causes the gas to ignite and burn prematurely. It is said that there is nothing like the difficulty in making joints that there is in a steam plant, but, at the same time, it is essential that the work should be done well. For if the air leaks in and the gas burns prematurely, it cannot give out its heat again when it is in the engine. Moreover, it leaves the producer in so hot a state that it must be again cooled down in the scrubbers, and is admitted to the engine as an incombustible or useless gas.

THE PRODUCTION OF STEAM.

One of the earliest difficulties with which the makers of suction gas plants had to contend was that of regulating the supply of steam to suit the needs of the producer. It is in the arrangement of the vaporiser that we find the greatest variation in producer design. Some makers place it inside the producer, and others as a water-belt surrounding the bottom of the fire. The advantage of the latter is that the producer at this point need not be lined with firebrick, and thus no adhesion of clinker can occur. It is also readily accessible for cleaning purposes. The former has the merit of compactness, the whole of the vaporiser being enclosed within the producer shell. The ratio of heating surface to volume is usually greater in the enclosed vaporiser, and so a smaller boiler is needed. Moreover, as less of the heated surface is exposed to the air, the losses by radiation may be expected to be less in the internal vaporiser than in the external type. Another method is to place the vaporiser outside the producer, and heat it by the gas (unburnt) after it leaves the producer. Of course this has advantages and disadvantages. On the one hand, it cools the gas more and saves water in the scrubbers; on the other hand, it may happen that the gas is not sufficiently heated to give the steam required, and it is absolutely essential that there should be enough steam or else there will be trouble by clinkering.

The steam supplied should be regulated according to the load at the engine. Now, although the load may vary very rapidly, it is obvious that the temperature of the fire cannot respond so quickly, and therefore with a light load there is danger of producing too much steam, and if this happens the fire becomes damped down, and we get the undesirable formation of carbon dioxide (CO_2). On the other hand, if the fire is damped down, and there comes a demand for full power, we get a poor quality gas, and cannot get full load off the engine. It therefore seems necessary that some method of regulating the steam supply according to load on the engine should be resorted to. In some plants, you will notice, regulating valves work from the engine, and these, as their name implies, regulate the steam admitted to the fire. Others have an arrangement by means of which a constant quantity of steam is generated, but when the load is varied this is blown off and not passed through the fire. This is, of course, wasteful. In some types the regenerative system is used. In these the sensible heat of the hot gases leaving the furnace is utilised to produce the steam necessary for the producer, or to heat up the water previous to its introduction into the vaporiser proper (*vide* "National" producer). Opinion seems to be decidedly in favour of utilising the sensible heat of the hot gases, not only because it returns heat which would otherwise be wasted, to the producer, but because the cooling down of the gas enables a greater weight of it to be drawn into the engine on the suction stroke, with the result that more power can be obtained from a given cylinder volume.

Yet another type of vaporiser, mostly used in Continental designs, is the tube vaporiser, placed outside the producer. In this design the gas, on its way from producer to scrubber, passes through an arrangement somewhat resembling a locomotive boiler. A cylindrical casing is divided into three compartments by two tube plates, the two outer compartments being connected by a tube or bank of tubes. In some cases the gas passes inside the tubes, whilst the water contained in the middle compartment surrounds them, and in others the water is inside and the gas passes outside the tubes, as in an ordinary water-tube boiler. There are objections to both these arrangements. If fire tubes

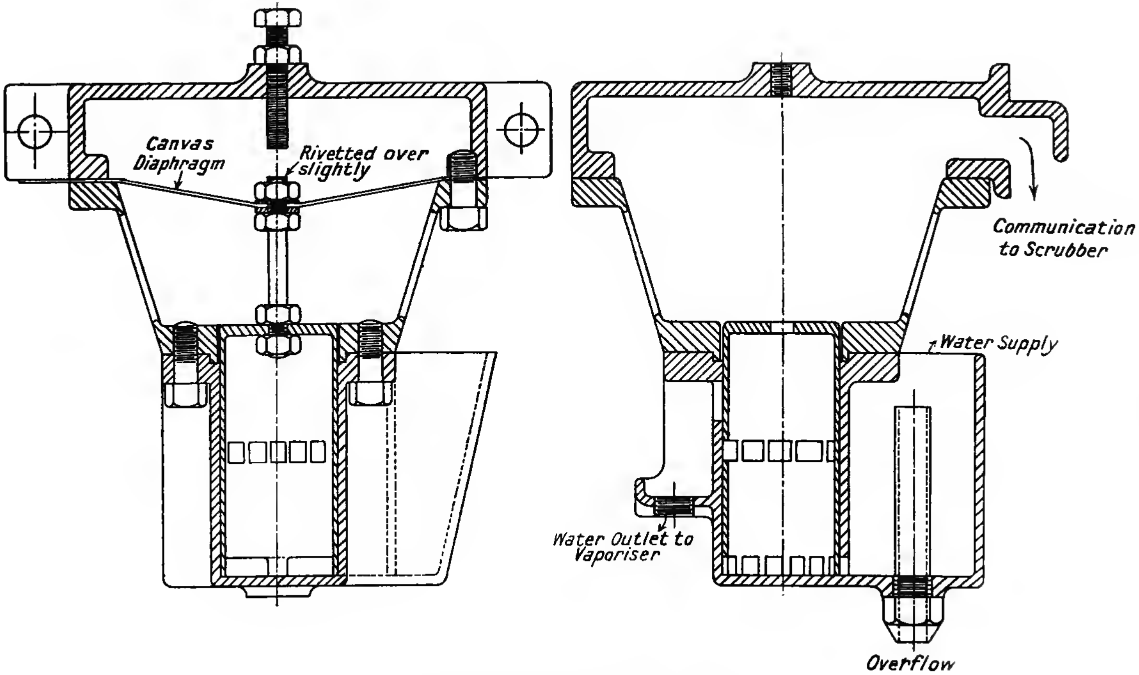


Fig. 11.—Automatic Water Regulator for Suction Plant.
(*For details of working see Appendix V.*)

are used, the lime salts present in the water are deposited on the outside of the tubes, where cleaning operations are impossible and the flow of heat from gas to water is retarded. If, on the other hand, water tubes are used, there is the drawback that they readily become clogged up by the deposition of lime and other matter present in the water, and their exterior surfaces are readily covered with tar and soot from the gases. The use of brass or copper tubes should be avoided, as they quickly become corroded by the ammonia and sulphuretted hydrogen contained in the gas.

A coiled pipe is used by some makers, somewhat like a flash boiler. This is open to the same objections as the water-tubes of the tubular type, with the addition that, being coiled, the inside of the tubes is not accessible for cleaning purposes (fig. 30).

Other makers allow the water to trickle over a hot surface. This type is immune from the above disadvantages, and has the further merit of simplicity of construction (see fig. 13).

In other designs the vaporiser is circular, in the form of an open-mouthed boiler. Sometimes it is made of cast iron, and in other cases of pressed steel. The merits of cheapness and immunity from corrosion are claimed for the former, and those of efficiency and superior durability for the latter (see figs. 5 and 12).

Regulation of Water Supply.—The requirements of the vaporiser are that the water supply be regulated so that it may never be deficient for the load and never in excess of what is required. Regulation is sometimes arranged to be done by hand, but automatic devices are certainly preferable. The most obvious method is to vary the amount of water sucked into the producer. Another way is to alter the air supply, as this changes the proportion of water vapour in the producer. The air supply can be adjusted either for quantity or temperature.

Mr Dowson and other makers cause the suction of the engine to draw the water into the vaporisers. Consequently we get at each suction stroke the amount required for the gas to be consumed. But this means that a flash vaporiser must be used. It is very advisable to have sufficient steam, and also to be sure that the quantity of the steam varies with the volume of the gas given off (see fig. 9, p. 18).

If suction gas producers were to be worked continually on full load, or even at one definite load, it would be an easy matter to regulate the air and steam supply. But it is the variation in the load which causes a variation in the draught of air through the producer.

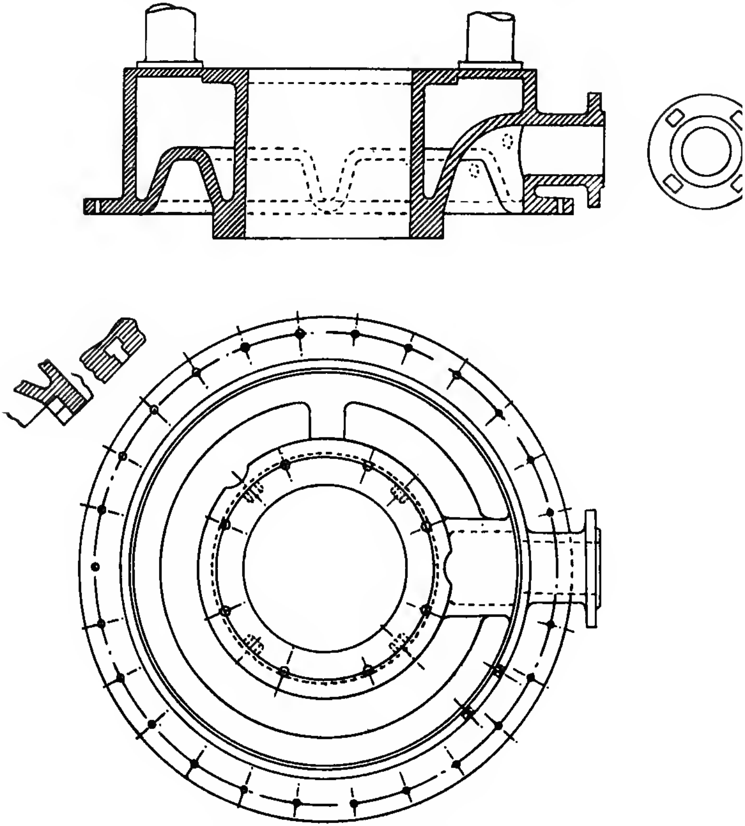


Fig. 12.—Circular Form of Vaporiser.

Were the steam supply to remain constant at light loads, there would be a great variation in the quality of the gas and the temperature of the producer.

As we have seen above, there are three ways of automatically regulating the water or steam supply. They are :—

(*a*) By automatically varying the amount of water sucked in.

(*b*) By varying the dry air supply and so reducing the proportion of water vapour introduced into the furnace.

(*c*) By varying the temperature of the air supply.

Mechanical devices for doing all of these things have been tried. They are usually controlled by the suction stroke of the engine. But on the whole it is found to be satisfactory under normal conditions to work without them. The times of light load are usually of short duration, and can generally be anticipated by an intelligent attendant.

The design of the vaporiser varies according to the plans for heating the air supply. The two parts of the apparatus are, to some extent, dependent on each other.

In the Crossley plant the vaporiser is in the bell (storage), and two cast iron segmented boxes on the grate level act as superheaters. Steam supply is controlled by means of cocks in the air space, and a secondary air supply is used (fig. 22, p. 86).

In the Dowson plant the vaporiser is made to form a double casing round the upper part of the producer body (see fig. 9). It is made to contain pieces of broken refractory material upon which the water may drip. There is a small chamber which is above the producer top, and this receives the water from the supply pipe. To this there is an internal overflow pipe, so that water is kept at a constant level. And this water passes into a circular pipe (not shown in diagram) round the top part of the vaporiser. In this there are a number of supplies which point downwards, and the water drops out according to the degree of suction. Air comes into the double casing and goes through the broken porous contents and takes up the water vapour. It is then led into the ashpit by a passage inside the outer casing of the producer.

The Tangye vaporiser is a cast-iron evaporator or boiler. It is of the "open-mouthed" type. It is placed on the top of the producer, and a fair amount of surface is presented to the hot gases as they pass through the exit pipe (fig. 28, p. 94).

It is to be kept full of water. The overflow drops to the ashpit, where the hot ashes and radiation convert it into steam.

Other vaporisers will be dealt with in detail in the description of their respective plants.

The Air Supply.—The preliminary heating of the air before entering the producer appears to be of great utility in keeping up a good fire. Its economy lies in the fact that the furnace has to supply less heat to raise the air to its own temperature, and also that, when heated by the outflowing gases, it returns to the producer some heat that would otherwise be wasted in the scrubber.

The heating of the air may take place either before or after the admixture with steam. In the former case, the air is usually taken through an annular passage surrounding the pipe through which the hot gases are flowing (*vide* "National" producer), and then, if further heating is required, it passes down an annular jacket surrounding the furnace, thus receiving the heat radiated from the firebrick lining.

In the second case, the air and steam are usually superheated by passing them through an annular casting which is arranged in the ashpit (Wiedenfeld producer).

The Water Seal.—When the hot gas passes from the producer it can be cooled by passing it through a cooling arrangement or radiator so that the gas is cooled by the air. But the gas must pass rapidly from the producer to the engine, and it must be dealt with quickly. Consequently it is impracticable to use any such device. The gas is therefore usually passed through a water seal.

The object of this is to prevent any diffusion of gas between scrubber and generator when the engine is shut down. The water seal thus effectually prevents the gas from blowing back into the furnace and so reduces the risk of explosion. In case of explosion the water seal would act something after the fashion of an escape valve. Figs. 5 and 7, pp. 11 and 15, show this clearly.

The Scrubber.—As its name implies, the scrubber is used for cleaning the gas before it is used in the engine. It consists of a cylindrical tower made of sheet or cast iron. It is divided into two parts by means of a grate or perforated partition, which supports a deep bed of coke or other porous material. The pieces are from 2½ to 3½ ins. in size. At the top there is a spraying arrangement which distributes the water all over the coke, down which it trickles and collects at the bottom of the tower, from which it is drawn off by a syphon into the seal box or waste pipe.

The usual practice is to allow the gas to flow into the bottom of the scrubber and out at the top. Thus the motion of the gas is in the opposite direction to that of the water, so that the deposit is naturally carried away. It follows, therefore, that the bottom layers of coke become more quickly clogged than the upper layers. An improvement in the present-day scrubber would be effected if means were provided for removing the bottom

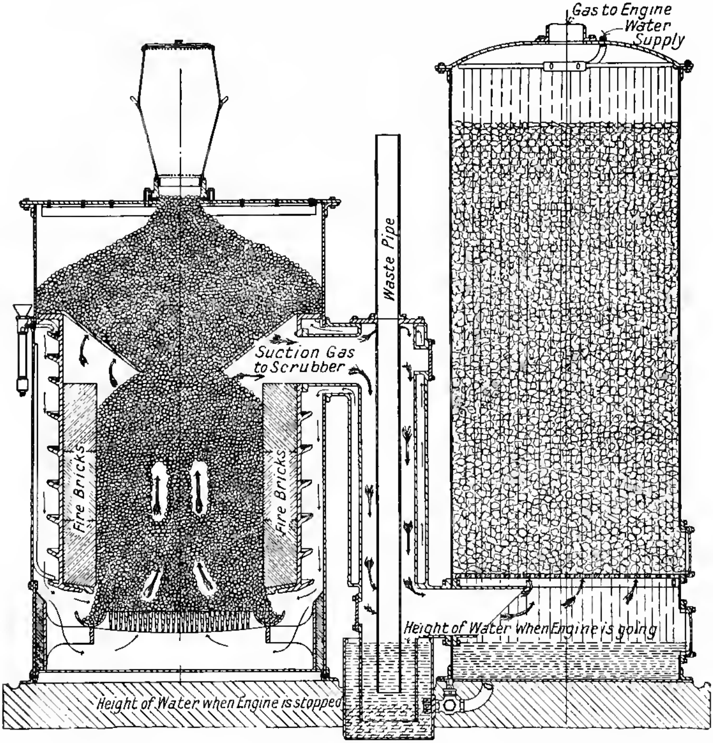


FIG. 13.—Producer Plant showing Water Seal and Levels of Water.

layers of coke without disturbing the upper. The coke at the bottom of the scrubber, also, should be larger than at the top, so that the choking effect would be reduced to a minimum.

As regards the dimensions of the scrubber, it has been shown by experience that the diameter of the scrubber should not exceed 36 ins., otherwise the flow of gas is not uniform over the cross section. The depth of coke should be about 5 or 6 ft. to cleanse the gas properly.

Many scrubbers are capable of improvement in the water supply. Too much is left to chance in the matter of water distributing itself evenly over the coke.

Open trays should be arranged, over the sides of which the water could flow, being guided all over the surface of the coke by small projections, to act as "dripping points." Or else a layer of smaller pieces to a depth of 6 or 8 ins. may be arranged on top of the main body of coke, so that the water is more evenly distributed throughout the mass.

The scrubber is also useful, however, for cooling the gas, as it abstracts the remainder of the heat carried away from the furnace, after the regenerative action on the water and air mentioned above. The heat thus removed is, of course, wasted. It may be asked, Why is it necessary to cool the gas before it enters the engine cylinder? Surely, the reader will say, some use might be made of the heat contained in the gas to drive forward the piston in the engine cylinder? The answer is simple. The volume of the gas varies with its temperature, and therefore we want it at low temperature, in order to draw as much of it into the engine cylinder as possible. If it could be done conveniently it would be an advantage to have the gas even cooler than when it emerges from the scrubber. There is another disadvantage in passing heated gas into the engine cylinder, and that is, the danger of back firing.

As regards the water consumption, about $\frac{3}{4}$ gallons per B.H.P. per hour for steam raising purposes should be used. If it is necessary to use more than $1\frac{2}{3}$ gallons per B.H.P. hour in the scrubber, it means that the latter is too small for the producer. This allowance of water per B.H.P. hour does not include the cooling water needed for the gas engine. The latter is, of course, usually arranged so that it can be used over and over again.

The Deodoriser.—The condition of the water after having fulfilled its function in the scrubber renders it unfit for further use, and up to the present time it has had to be run away to waste. In places where water is scarce or high in price, this water consumption has operated against the putting down of a "suction" gas producer.

To remove this obstacle Messrs Tangye inform me that they have recently perfected an invention by which the impurities of the water are entirely removed, so that the same water can be used over and over again.

The total water consumption is thus very small, amounting only to that used in the vapour chamber, which is about half a pint per B.H.P. per hour, and the wastage caused by evaporation in the process of cleansing. Feed water required for vaporiser varies with design of same. In the larger plants, two scrubbers are sometimes used to give the necessary cooling and cleaning effect.

In cases where it is necessary to have a very clean gas, or when coal is used which is somewhat softer than anthracite, and supplies an appreciable amount of tar, a dry scrubber is often employed in addition to the above. This consists of a cylindrical casing, provided with perforated shelves, on which are placed a thin layer of sawdust or wood shavings, which do not oppose a great resistance to the flow of gas. The presence of water, however, causes these to swell up and offer a greater resistance to the gas. Consequently these have to be renewed somewhat frequently (fig. 30, p. 99). On leaving this the gas passes into the expansion box.

The Expansion Box.—This is a reservoir placed between the scrubber and the engine. It takes the place of the gas bag used in a pressure plant, and is for the purpose of reducing the suction of the engine on the producer during the suction stroke, and thus enabling a more even flow of steam and air through the fuel during the four strokes of the cycle. It is, of course, very much smaller than the gas holder used with pressure plants, and should preferably be three to four times the volume of the engine cylinder. In many cases the volume of the piping between scrubber and engine is sufficient for this purpose.

Features of a Good "Suction" Producer.—The construction must be as simple as possible, consistent with efficiency.

By having a suitable steam raiser and the capacity of the generator rightly proportioned to the cylinder volume, when a change of load on the engine occurs, the producer should automatically respond to the new conditions, and not require adjustments of its steam or air supply.

The generator should be provided with a poking hole and suitable cleaning doors, making the interior of the generator easily accessible, so that clinker can be removed while the plant is in operation. This is an important attribute, as it enables an engine to work continuously for an indefinite period, without the requirement of a stand-by generator.

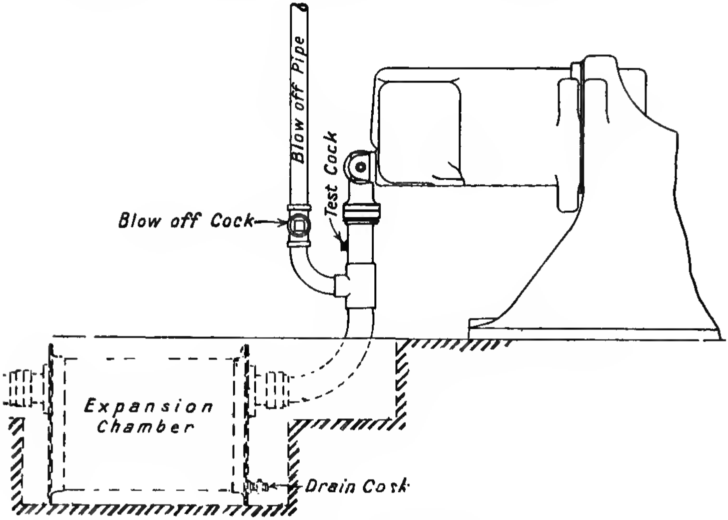


FIG. 14.—The Expansion Box.

The firebrick lining of the furnace should be arranged so as to be quite accessible, so that clinkers can be removed without trouble. Moreover, if the interior is not easy to get at, the lining is likely to be badly done in the first instance. There will be defective joints which let in air and produce intense heat in the vicinity, thereby spoiling the brickwork and forming clinker.

The hopper, as we have seen, should be designed so that no air can find its way into the furnace while charging. The vaporiser should also be accessible, easily cleaned, and of as simple a form as possible.

Another important point is, that the resistance to the flow of gas, as exemplified in the size, length and number of bends in the piping of the plant, should be reduced to a minimum. It should be remembered that the vacuum in the engine tending to suck gas from the producer is very small; moreover, the piston of the engine moves so rapidly that considerable wire-drawing is bound to take place, and a less weight of gas enters the cylinder than would otherwise be the case. Further, when the piston is nearing the end of the suction stroke it is moving slowly. Consequently in a pressure plant, where there is a pressure tending to force gas into the cylinder, a considerable weight of gas is able to enter at this part of the stroke. In a suction plant this does not exist, and as there is only the reduced pressure in the cylinder to pull the gas through the producer, scrubber, and connecting pipes, the engine does not get its full supply of gas. It is therefore important to reduce the resistances in the plant to a minimum by making the pipes short, of ample size, and as straight as possible. The negative pressures in a suction plant working under ordinary conditions are shown in fig. 15 on next page.

FUEL AND TESTING.

The Fuel Used.—Anthracite is certainly the most suitable coal for suction gas producers. Very few attempts have been made to work with a fuel that is not, comparatively speaking, dry and which cakes. Mr Thwaite states that a bituminous coal for a suction gas plant should not contain more than 15 per cent. of volatile matter. But the difficulty with bituminous fuel—in addition to the fact that it cakes and clogs—is that the gas, when it is distilled, absorbs so much latent heat that there is a danger that there will not be a sufficiently high temperature to completely convert all the CO into CO_2. Mr

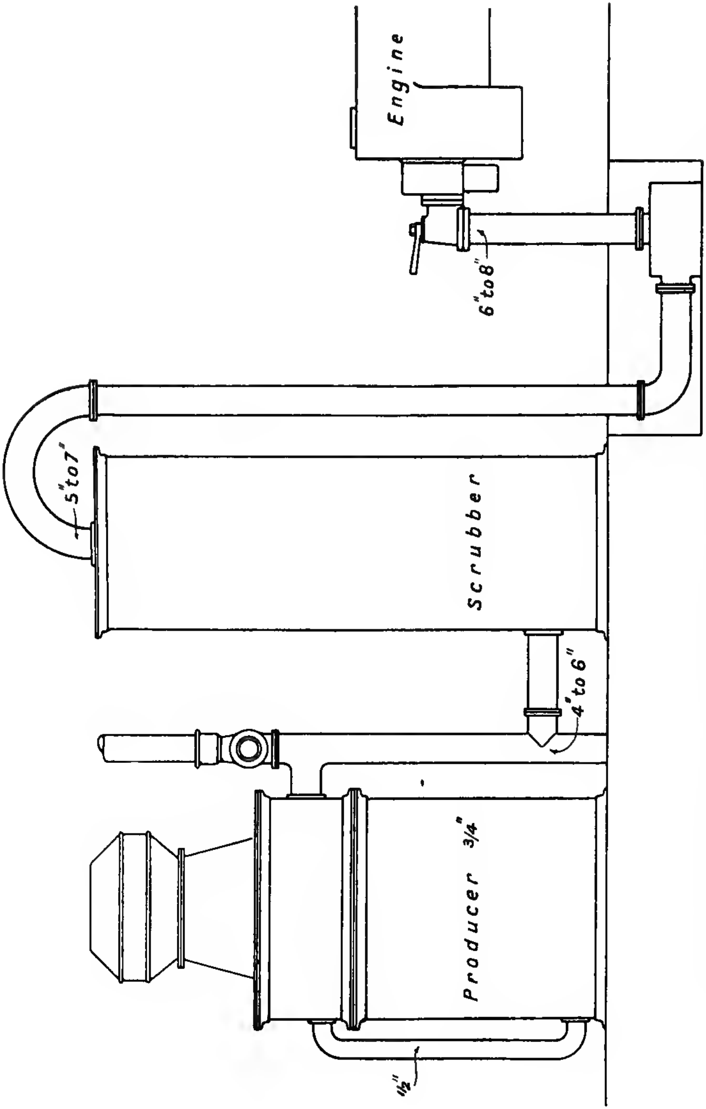


FIG. 15.—Negative Pressures in inches of water, recorded by Water Gauges fixed in positions shown.

Thwaite has invented a producer for bituminous coal, in which there is a secondary air supply. This raises the fuel to incandescence in order that the hydrocarbons may be split up and so fixed in the gas. And it should be noticed that in such a producer the burning must be downwards. The green fuel should be put in at the top. There it gives off its gases, which pass down through the hot fuel below. But as this temperature is not sufficient to convert the volatile matter into fixed gas, air is admitted a short distance down. And it is in this zone, where there are high temperatures, that the hydrocarbon vapours are fixed.

With small gas-engines the total amount of fuel required was not at first sufficient to make builders of suction gas plants desire to obtain further economy with a possible uncertainty with regard to the cleanness of the gas and its freedom from tar. Anthracite and coke gave less trouble than bituminous coal. The problem of the use of bituminous coal is more complicated than it appears, and it would appear that, until the general body of engineers know a great deal more than they do at present about suction gas producers, it is better to use anthracite, except under special conditions. For the gas must be free from tar, otherwise it will foul the valves and passages of the gas engines. And there must be no soot.

Speaking generally, therefore, we may say that coals which cake are unsuitable for suction gas producers. For if the coal cakes there is a danger of making an inferior gas. So that it is accepted that the extra cost of attendance and tar extractors is such an item that anthracite or coke is nearly always used.

In a gas producer it is important to make as little clinker as possible, so that it is usual to specify anthracite which has a low percentage of ash.

Such an anthracite has the following analysis :—

Fixed carbon, 94 per cent.
Ash, 2 ,, ,,
Volatile matter, 4 ,, ,, with a trace of sulphur, indicating a high proportion of carbon with the minimum of ash and volatile products.

But besides the quantity of ash present in the coal, it is important to take into account its composition. The basic oxides (those of iron, calcium, etc.), under the influence of high temperature, have a tendency to combine with the silica present in the ash, or in the lining of the producer, forming silicates which are more or less fusible, according to their composition. If these remain in the form of ash, or if only partially fused, it can easily be removed; but if it fuses, it will adhere to the lining of the furnace, and then becomes very difficult to remove; besides which, it becomes larger by the deposition of more clinker (after the manner of a "scaffold" in a blast furnace) until it blocks the fire. When it is necessary to use coal which forms silicates of this nature, it is advisable to reduce the temperature in the producer by admitting more steam. The sizes of fuel mostly used in gas producers are "nuts" which have passed through a 1¾-in. diameter hole, but will not pass a ¾- or 1-in. square hole; and "peas" which have passed through the latter but will not pass through a ⅜-in. square hole.

The calorific value of this anthracite is about 13,000–14,000 B.T.U. per lb.

The price of Welsh anthracite has recently advanced, and it is now costing, delivered in Birmingham, 25s. per ton. Even at this price the fuel cost on engines of moderate power is at the rate of about one-eighth of a penny per B.H.P. per hour.

Scotch anthracite is much used on account of its cheapness, being delivered in Scotland at about 10s. per ton. As it contains more volatile matter, however, it is necessary, with some brands, to employ extra scrubbing apparatus, to prevent the accumulation of tar on the engine valves. There is also rather more ash and clinker produced from it, which necessitates a little extra attention being given to the generator than when Welsh coal is used.

On gas engines in combination with "suction" producers consuming Scotch anthracite, the cost of fuel works out at the very low rate of $\frac{1}{20}$d. per B.H.P. per hour.

Coke is also being successfully used in places where anthracite is not available or its price is prohibitive. Coke is the porous, non-volatile residue left when coal is heated without access of air. Large quantities of this are produced in the manufacture of town gas. This "gas coke" varies in its composition, and, as the original coal is selected for its gas-making rather than its coke-making qualities, it may contain a good deal of ash. A good gas coke contains about 89 per cent. of carbon and 8 per cent. of ash—no volatile matter, of course, being present. A better coke is that produced in coke ovens for use in blast furnaces and cupolas, as it is purer, denser and stronger than gas coke, as carbonisation is carried on more gradually and with a view of obtaining a good coke. This contains more carbon and about half the quantity of ash and less sulphur than we get in gas coke. However, the latter is more often used, as it is cheaper and more readily obtainable than oven coke.

In considering the use of coke, it must be borne in mind that the consumption of it is about 25 per cent. more than that of anthracite; also that it involves a loss of about 5 per cent. in power, owing to the gas produced from it being somewhat inferior in quality to that generated from anthracite.

Messrs Tangye have lately constructed a "suction" producer for the utilisation of *charcoal* as the working fuel, from which excellent results have been obtained. The consumption of it, as in the case of coke, is about 25 per cent. more than that of anthracite.

Testing a Suction Plant.—Having devoted some time to the consideration of the nature of the fuel used in a suction plant, we are now in a position to consider the amount of power that can be obtained for a given expenditure of fuel in plants by different makers. But before doing so, it may be advisable to give some account of the measurements and observations necessary in testing a plant of this description. The weight of coal used is, of course, one of the most important items. It is weighed out in large or small lots, according to the size of the plant, and the total quantity used can thus be ascertained at the end of the trial. After weighing out each quantity of coal, a small sample should be taken from the same part of the heap. This, at the end of the trial, assumes rather unwieldy dimensions. The lumps are then broken up to a fairly uniform size and divided into four equal parts. One quarter is retained, broken up into smaller pieces, and again quartered. This process is repeated until about 1 lb. of coal is left, which may be taken as an average sample of the coal used throughout the trial. A portion of this is then burnt in a calorimeter, preferably one of the bomb type (for a description of the Mahler bomb calorimeter, see Appendix I.). The calorific value of 1 lb. of fuel is thus obtained. If the producer is started hot, the fuel at the end of the run should be at about the same level as it was at the beginning, so that the fuel actually consumed during the trial can be ascertained.

The water used in the vaporiser is measured by a water meter, as is also that used in the scrubber. If the inlet and exit temperatures of the latter are taken at regular intervals, the heat rejected in the scrubber may be found. The gas then passes through a gas-meter, the readings of which are also taken at regular intervals, to ascertain whether the gas was produced and consumed at a steady rate. If an engine is not available, a fan may be used to suck the gas through the plant. This has the incidental advantage of securing a steady load. If a gas-holder is used, it should be kept at a steady level throughout the trial, so that the rate of consumption may be the same as the rate of production. Samples of the gas should be taken at regular intervals so that the final sample may form an indication of the quality of the gas produced throughout the trial. This is analysed to find out the average chemical composition of the gas. The calorific value of the gas is ascertained by passing a small quantity of it through a gas meter and burning it in a Junker calorimeter (Appendix I.). The value thus obtained may be checked by calculation from the chemical composition of the gas. From the quantities thus obtained we can find the heat efficiency of the plant, the weight of fuel required to produce a given volume of gas, the running costs of the plant, and other important details.

Practical Points in Gas Producer Testing.—Having discussed the testing of a producer plant in general terms, we will now devote attention to the particular points to be noted in running such a test. Mr S. S. Wyer cites a number of such points, the most important of which I will now put before you. First of all, the specific object of the test should be determined, whether it is for the purpose of ascertaining the capacity of the producer, its efficiency and defects, or the effect of changes in design, proportions, or operations, and the trial prepared for accordingly. The producer should then be carefully examined, the particulars and dimensions noted, and special features illustrated by sketches. If possible, a drawing should be obtained, or made from the particulars thus ascertained. The general condition of the producer and its equipment should now be noted, and a record made of such facts as bear upon the objects in view. If the object of the trial is to ascertain the maximum economy of the plant, the producer and all its accessories should be put in first-class condition. All clinker should be removed from the grates and lining, and dust, soot and ashes should be cleaned out as much as possible. All air leaks must be tested for by means of a candle flame, and stopped up when found. In short, all defects due to the condition of the producer should be removed as completely as possible, so that the producer may have a chance of showing what it can do under the best conditions. The character of the fuel to be used must then be determined. If the efficiency or capacity of the producer is to be compared with other producers, the fuel should be of some kind which is commercially recognised as a standard. The calibration of the apparatus to be used is a most important point, as on this depends the accuracy of all the measurements made throughout the test. The scales, thermometers, pressure gauges, anemometers, etc., should be carefully compared with standards, and, if necessary, error curves plotted. If a thermo-electric pyrometer is used, it must be calibrated with the same lengths of wire, and the same resistance used in taking the readings.

As regards the duration of the test—if this is made to ascertain the maximum economy or minimum capacity of the producer, the duration should be at least twelve hours of continuous running, after the producer has been brought up to its normal working condition.

When stopping the test, the conditions of the producer should be as nearly as possible the same as they were at the beginning. The fire should be the same in quantity and condition, and the flues, walls, etc., should be of the same temperature. In no case should the fires be drawn, as is often done in boiler tests, but if it is necessary to shut down for cleaning, it is advisable that the test should cover one continuous phase only. As we have seen, arrangements should be made to utilise the gas so that the rate of generation shall be constant during the test, and uniformity of conditions should prevail throughout the test. Every event connected with the trial should be noted, however unimportant it may appear. The time of every occurrence, and that of taking every weight and observation, should be recorded, so that the conditions at every part of the test may be accurately known. The amount of steam generated, and consequently used in the producer, must, in the case of a suction plant, be calculated from the composition of the gas, as we have no auxiliary boiler, and consequently cannot directly determine the steam produced or the heat consumed in its production. From the analysis of the gas we know the percentage of hydrogen present. Now this hydrogen must come from three sources, viz. the coal, the moisture in the coal, and from the steam. All these quantities are known except the latter, which can consequently be determined and the amount of steam used in the producer thus calculated.

To determine the grate efficiency of the producer a sample of the ashes and refuse of the generator must be taken. These will generally be wet before being drawn from the producer, especially if this is of the water-seal type. After the test the ashes must be raked out and immediately weighed, a sufficient sample for chemical analysis being weighed out in the meantime. This large sample must be allowed to dry in the air until it reaches a constant weight; a laboratory sample is then taken and the residual moisture determined. The amount of incombustible material must be accurately determined, and in this way the grate efficiency of the producer is found. The method of sampling the coal has been already explained. In sizing the sample it should be crushed to pass through a ·5-in. mesh and then air-dried for twenty-four hours or more, long enough to ensure that the quantity of moisture remaining will vary less than 1 per cent.

For the determination of water-vapour, tar, and soot in the gas, the use of the following apparatus, designed by Professor Lord, is advised. Referring to fig. 16, B is the sampling tube made of ·5-in. iron pipe which is placed in the gas flue. This is surrounded by a jacket A, through which live steam is passed by means of the pipe connections C and D. The object of this is to

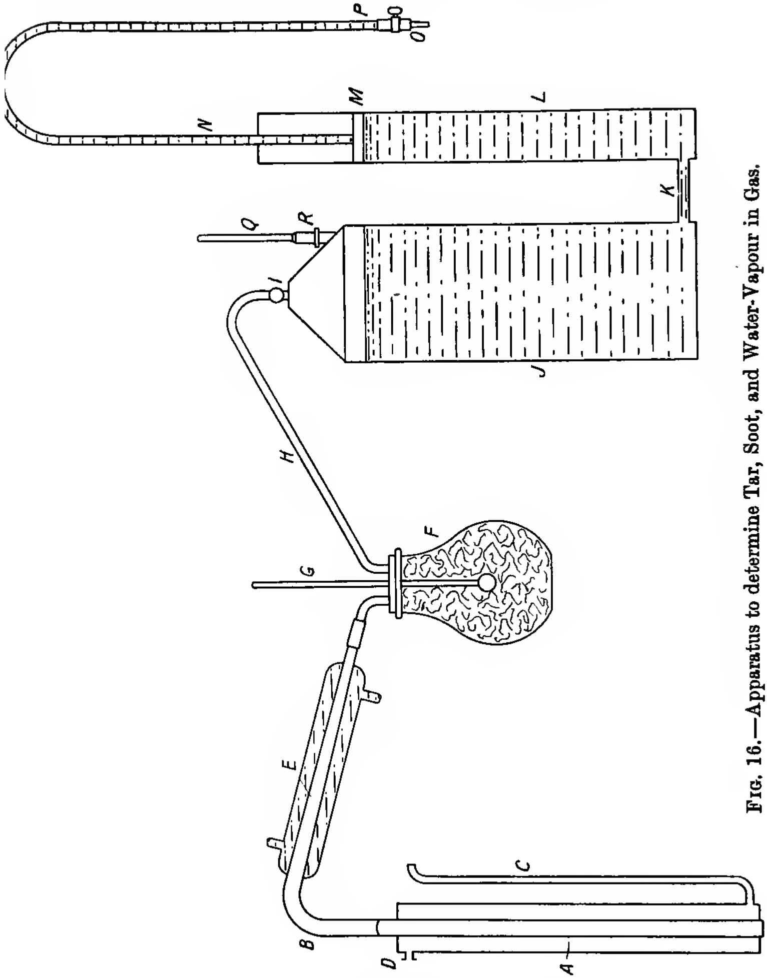


Fig. 16.—Apparatus to determine Tar, Soot, and Water-Vapour in Gas.

keep the temperature of B below the point at which the iron would act on the CO_2, but above that at which the moisture of the gas would be condensed. After leaving this pipe, the gas passes through a condenser E, through which cold water is circulated, into a flask F, which is filled with ignited asbestos fibre, and contains a thermometer G. The water tank J is connected to F through a valve I, by means of a rubber tube H. This tank is also fitted with a small tube in which there is a thermometer Q. The object of the valve R is to allow the thermometer to be removed when gas is in the tank J. There is another water tank L, connected to J by means of the tube K. On the top of the water in L is a float M which is connected by the glass tube N (acting as a syphon) to the nozzle O, which has a pinchcock P, on the rubber connection. The object of the float and glass tube is to keep a constant head above the nozzle and thus ensure a constant flow through it.

To start the apparatus proceed as follows:—Disconnect the rubber tube H and fill the tanks J and L with water, until it overflows at the valve I. Fill the syphon N with water and close the stopcock P. Attach the tube H to the stopcock I, and circulate water through the condenser E, and steam through the jacket A. Then open the valve P. The water will now be drawn out of the tanks L and J, and these will act as an aspirator, drawing gas through the apparatus as far as the top of the tank J. The water in excess of the saturation of the gas at the temperature of the small flask F is condensed, and any tar and soot retained in the ignited asbestos. After the test, the flask and its contents are weighed, and the increase in weight during the test gives the weight of tar and water condensed from the volume of gas which has passed through the flask. This volume may be determined by running water from O into a graduated vessel, the measurement thus obtained being an indication of the volume of gas drawn into J.

The water remaining in the gas after passing out of the flask F is then calculated from the temperature of the issuing gas (which was saturated with water vapour) by means of the ordinary saturation tables. The water in the gas is then the sum of the permanent vapour and that condensed. The water in the flask is found by drying the contents over sulphuric acid to constant weight, and determining the loss. The dry contents are then ignited, and the further loss estimated as soot and tar. The following calculation shows the method of obtaining the water-vapour present in the gas, from the above observations:—

B = Barometic pressure.
T_t = Temperature of gas in tank.
T_v = Temperature of gas in flask.
V_t = Vol. of wet gas in tank at temp. T_t.
V_s = V_t reduced to 0° C. and 760 mm.
V_d = Vol. of dry gas at 0° and 760 mm.
B_t = Tension of water-vapour at T_t.
B_v = Tension of water-vapour at temp. T_v.
W = Weight of 1 cubic unit of water-vapour at temp. T_v.
W_v = Weight of water-vapour condensed in flask.
W_t = Weight of permanent water-vapour in vol. V_s.

Then $$V_s = \frac{V_t\,(B - B_t)}{760\,(1 + {\cdot}00366\,T_t)}.$$

Percentage by volume of water vapour in flask $= \frac{B_v}{B}$.

Percentage by volume of water vapour in $V_s = \frac{B_t}{B}$.

Then $$V_d = V_s\left(1 - \frac{B_t}{B}\right).$$

Total volume of permanent water-vapour in $V_s = V_s\,\frac{B_v}{B}$.

Therefore $W_t = V_s\,\frac{B_v}{B}\,W$.

Now $W_t + W_v$ = total weight of water carried off in vol. V_d of gas. Therefore, from this the amount of water, tar, and soot per pound of coal can be calculated directly.

Test by Mr Mathot.—To show how a gas engine and producer test is usually recorded, I will now give a few extracts from the report of a test on a Tangye plant by Mr R. E. Mathot. The object of the test was to determine the power, manner of working, and consumption of fuel of three gas engines and suction plants. The fuel consumptions were ascertained under regular working conditions. With that object, the producers were charged with fuel to a predetermined level at the commencement of the trials, after clearing the fire-bars and consolidating the fuel by thorough poking. The quantity of fuel added during the trials was noted, and at the end of the trial the generator was refilled to the original level and the weight observed previous to poking and consolidating the fuel and clearing the grate. Then, after these operations, the generator was filled up again and the total weight noted.

I shall only tabulate the results of one engine.

Engine reference letter		1 S
,, number		11,035 B
Diameter of piston	ins.	10
Stroke	,,	19
Revolutions per minute		190
Diameter of flywheels	ins.	63$\frac{1}{1}\frac{3}{8}$
Thickness of rope—		
(1) For positive load	mm.	33
(2) ,, negative ,,	,,	13
Radius to be taken into consideration—		
(1) For positive load	mm.	827
(2) ,, negative ,,	,,	817

		Full load.	Half load.
Average positive load	lbs.	231·70	129·83
,, negative ,,	,,	34·7	25·0
,, speed	Revs. per min.	197·06	197·58
Effective work at rate of 3300 ft.-lbs.	B.H.P.	19·736	10·711
Average of mean effective pressures	lbs. per sq. in.	74·811	72·962
No. of useful cycles	per cent.	84·9	54·3
H.P. expressed in accordance with useful cycles		23·5516	14·7298

Fuel.

Sort and Origin.	Scotch Anthracite (Baird's Gartshaw).	Welsh Anthracite (Tremsaran).
Composition—		
Carbon	87·4	89·60
Hydrogen	2·6	3·25
Oxygen and nitrogen	4·2	3·95
Ashes	5·8	3·20
	100·0	100·0

		Full load.	Half load.
Methods by which Fuel Consumptions were obtained—			
1st. Gross hourly consumption measured before consolidating fuel by poking and cleaning fire .	lbs.	14·605	8·862
2nd. Do. measured after these operations .	,,	15·505	9·987
B.T.U.'s expended per hour (2nd method) .	,,	220,060	141,742
Mechanical Efficiency	per cent.	83·8	72·7
Consumption per effective H.P.—			
Fuel gross, as per 1st method .	lbs. per hour	·740	·827
,, ,, 2nd ,, .	,,	·785	·932
Thermic Balance—			
B.T.U.'s expended for combustion of coal per B.H.P. .		11,150	13,233
,, absorbed by cooling water of engine per B.H.P.		3,345	2,840
Corresponding Proportions of Heat Expended—			
By effective work	per cent.	22·9	19·3
,, losses through cooling water . .	,,	30·4	21·7
,, ,, exhaust, radiation and producer (by difference)	per cent.	46·7	59·0
		100·0	100·0
Miscellaneous—			
Residuals gathered under grate of generator, after tests for the entire duration of same :—		Full load.	Half load.
Good coke	lbs.	1·997	1·9983
Ashes	,,	3·994	2·1382

Tests on the Daniels Suction Gas Producer.—This firm manufacture suction gas plants for anthracite, coke and charcoal fuels. The cost of the installations varies somewhat, but under ordinary conditions the cost of putting in one of the 50 B.H.P. suction gas plants, including foundations for a standard straightforward job, would be about £104—that is, for the plant only. For the suction plant of an engine of 50 B.H.P. complete the capital cost would be about £450, and the cost of running this set at full load for the fuel would be about 5d. to 6d. per hour. This is, therefore, £2 per B.H.P. for the plant and foundations, and £7 per B.H.P. for the gas engine and piping. The cost of a 100 B.H.P. plant only would be about £108, and the cost of engine and plant complete with two two-cylinder engines side by side, including foundations, would be about £800. The cost of running this set for fuel only would be not greater than 1s. per hour. This firm state that for a large size Premier scavenger type engine, the fuel consumption at full load gives something slightly under ·6 of a pound per B.H.P.

per hour. I give here the figures of two typical tests. Among tests which have been run by this firm there is one from Messrs Elcy Bros., at Edmonton, London, N. This was a 50-H.P. suction gas plant. A full week's test of six hours on the producer showed that the anthracite coal used, 1975 lbs. (at 24s. 6d. per ton), cost £1, 2s. 11d. The town gas for a like period on an average of six weeks cost £2, 16s. 10d. (price of town gas not given). Another firm, Messrs Howard Martineau, of Hemel Hempstead, installed a plant of 30 B.H.P., and in six months obtained the following figures. They had an old engine using gas at 3s. 8d. per thousand cubic feet, and the cost of fuel was £74, 4s. 6d. The new plant for a similar period consumed anthracite peas at 27s. 9d. per ton delivered, and the fuel cost £13, 10s. 6d. Thus they were able to show a saving of about 82 per cent. over town gas. It may reasonably be asked in what condition was the old engine, and also whether it is possible that there was any real variation on the load during the two six-month periods.

I give below the results obtained in official tests on two larger plants by the same makers.

Official figures of test of 4-cylinder (4V) high-speed (320 r.p.m.) vertical gas engine by Messrs D. Stewart & Co., Ltd., Glasgow, coupled to Daniels 150-B.H.P. suction gas producer.

Date	30th January 1907.
Fuel used	Scotch anthracite.
Calorific value of fuel	13,167 B.T.U. per pound.
Duration of test	4·25 hours.
Pounds of coal per hour	118·6.
Average B.H.P.	151·5.
Average KW. load	101.
Pounds of coal per KW. hour	1·17.
Pound of coal per B.H.P. hour	·8.
Total water used in producer and scrubber	7240 lbs.
Water per B.H.P. hour	11·13 lbs.

This trial was of rather short duration, and these figures might be exceeded in a longer test.

Some of the tests gave a fuel consumption of ·76 of a lb. per B.H.P. per hour.

I have here a record of the results obtained on a 300 B.H.P. "Daniels" suction plant as tested by the Premier Gas Engine Company, and the conclusions arrived at by the latter as the result of this test.

Official Test of a two weeks' test on a 300 B.H.P. "Daniels" suction plant (2–150 B.H.P. units coupled) and 300 B.H.P. "Premier" twin cylinder scavenger type "ood" engine, with flywheel and dynamo carried on extended crankshaft for direct electrical load.

Coal Consumption.—Two qualities of coal were used, namely:—

(1) Anthracite nuts (from the Great Mountain Colliery) costing 25s. per ton at pit.

(2) Anthracite peas (from the Great Mountain Colliery) costing 20s. per ton at pit.

Of these the former worked better in the producer than the latter, and there was practically no waste with it, whereas there was considerable waste with the latter before the coal was put into the producer, as it contained some very fine pieces that had to be riddled out. The figures for coal consumption are based on the coal actually fed into the producer.

These figures are worked out in three ways. First, the coal actually used during running time; second, that used during running time plus the loss while standing at night; and third, these two figures added to the loss of coal when the whole fire is taken out of the producer.

The figures are very good, as the average consumption for the whole corresponds to—

(1) Coal used running time (nuts), 0·7 lb. per B.H.P. hour.

(2) Coal used with 12 hours' stand-by loss added, 0·77 lb. per B.H.P. hour.

(3) Coal used with stand-by losses and cleaning out fires once a week, running time 12 hours per day, 0·8 lb. per B.H.P. hour.

The gas was not quite uniform in quality, and sometimes was too hot, which had an adverse effect on the power, but these defects were no doubt greatly due to the trouble with the water supply, the blocking of the sprinklers preventing a thorough cooling of the gas in the scrubbers, and for that reason more water than necessary was run through the jackets round the gas-cooling pipes, which reduced the water temperature, and consequently the quantity of steam formed in the vaporiser, so that the amount of hydrogen in the gas was less than normal at these times. The gas was analysed at different times during the test, and it was found that in one or two instances the calorific value was much below 130 B.T.U., which should be the minimum in normal running.

Nevertheless the engine carried a good load while the gas was below normal. The results of the test are conclusively in favour of the larger coal.

It is seen from the above test that the total fuel consumption is ·8 lb. per hour per B.H.P. With the anthracite nuts at 25s. per ton, the cost of running therefore was ·107d. per B.H.P. hour, or 9·3 B.H.P. hours could be obtained for 1d. With the cheaper fuel at 20s. per ton we should get 11·6 B.H.P. hours per penny, or the cost would be ·086d. per B.H.P. hour.

National Plants Fuel Consumption.—These plants are so designed that either Welsh or Scotch anthracite, gas coke, or charcoal may be used. It should be stated that when either of the two latter fuels are used they must be of fairly good quality, clean and well carbonised. Several hundreds of plants have been at work on these various fuels, and it is now possible to gain such experience as will enable the makers to guarantee certain definite results with either. This firm guarantee a fuel consumption of 1 lb. per B.H.P. per hour on a continuance test run with anthracite, and 1¼ lbs. per B.H.P. per hour under similar conditions with good gas coke or charcoal. The usual method of measurement employed for such guarantees is to fill the generator with fuel to a certain level at the commencement of the trial, and bring it back to the same level at its conclusion. The fuel which has been fed into the generator in the meantime is carefully weighed. This, of course, exactly resembles the methods employed on boiler trials, and seems a perfectly fair method of gauging the consumption. Naturally, the advice of the makers should be sought concerning the most economical fuel to be obtained in the various districts, as they have usually mapped out the areas, and are well acquainted with points which might be overlooked by local engineers or manufacturers.

In the Royal Agricultural Society's trials at Derby (1906), the "National" producer used 1·04 lbs. of anthracite per B.H.P. hour during a fourteen hours' test on full load. In the half load trial with anthracite (six hours), the same plant required 1·55 lbs. of coal per B.H.P. hour, and in a nine-hour full load trial with coke fuel it consumed 1·21 lbs. of fuel per B.H.P. hour.

Water Consumption.—Water must be supplied to all producers for two different purposes. There must be a constant stream of cold water continually running through the scrubber in order to keep the latter cool. There must also be a similar supply which is required for making steam in the generator. It may be accepted that for this plant the total consumption for the two purposes is about 1¼ gallons per B.H.P. per hour. A little more water is required when the fuel gives off tarry vapours. The water may be obtained from a river or canal close at hand, in which case a small pump is required to draw the water off, and with the same source of supply a pump can be used for cooling the gas engine. If there is no such source of supply available, then it is possible to use a cooling tank, and the water for the scrubber is circulated over and over again. In this case it is necessary to use a suitable deodorising medium in the tank.

In the R.A.S. trials (1906), the following water consumptions were obtained from the above plant:—

Full load trial (anthracite), fourteen hours, gave 1·14 gallons of water per B.H.P. hour.

In the half load anthracite trial (six hours), the consumption was ·52 gallon per B.H.P. hour.

The full load trial with coke fuel gave a consumption of 1·40 gallons of water per B.H.P. hour.

Test on a "Watt" Suction Gas Producer 20 H.P.—This plant was supplied by James Watt & Co., to the instructions of the Engineer, E. J. Silcock, Esq., M.Inst.C.E., Leeds, and consists of two suction gas plants of the "Watt" patent type, No. 2 size, supplying gas to two horizontal gas engines of 16·5 B.H.P., running at 220 revolutions per minute, each having a heavy flywheel 5 ft. 6 ins. diameter, outer bearing to crank shaft, balanced cranks, adjustable magneto ignition, and fitted with compressed air starter.

These engines drive two sewage type centrifugal pumps, having 5-in. suction and delivery branches. They are driven by belt from the engines, and are each capable of raising 25,000 gallons per hour to a total height of 37 ft.

The pumps discharge into a revolving screen (driven from either gas engine as required), and from the screen into bacteria beds or to a storm-water reservoir. A power-driven air pump is provided for charging the pumps, and the whole plant has been put to work in less than ten minutes.

In view of the difficulty experienced in starting with some plants, it is of interest to note that there is no town gas near the pumping station, so that all starting, etc. is done from the suction plant direct, thus showing that the "Watt" patent plant provides suitable gas for starting as well as running.

The plants were carefully tested by the engineer on August 15th and August 16th, 1906, and the figures given here show the economy obtained :—

ENGINE BRAKE TESTS.

	No. 1.	No. 2.
Average revolutions per minute . . .	215·5	219·3
Explosions per minute	97·5	95·65
Indicated horse-power	18·44	19·81
Brake horse-power	16·76	17·1
Efficiency of engines (mechanical) . .	90·8%	86·6%
Coal used per brake horse-power per hour .	0·954 lb.	0·66 lb.

The cost of running on anthracite at 25s. per ton is thus ·128d. per B.H.P. hour in first test and ·0893d. in the second.

Taking the two engines together, it will be seen that the average coal consumption was 0·807 lb. per B.H.P. per hour, which is an exceptionally good result for such a small plant.

The pumps and engines were also tested together, delivering over a measured weir, and the results were found to confirm the above figures.

The following is a description of a test carried out by Mr G. R. Rowles on a suction plant (make and capacity not given). Mr

Rowles supplied these figures during the discussion following the lectures.

On Thursday, June 4th, 1908, the plant was shut down at 9·30 p.m., the hopper was filled and left until the following day, when the plant was started up at 8 a.m. The following consumptions of anthracite peas took place during the test:—

	Friday, June 5th.	lbs.
8 a.m.	Stand-by and blowing up	40
,,	Engine started: load (130 amps. 224 V. = 27 kw.)	40
12 ,,	,, ,, ,, ,,	100
1 p.m.	Hopper filled, engine shut down Plant cleaned out.	20
2 p.m.	Engine started, hopper filled	120
4 ,,	,, ,, ,,	80
(	,, ,, ,,	80
	Total coal consumption, including stand-by and cleaning out	480

Ash and clinker	60 lbs.
Engine load, average	29 kw.
Coal per hour (9 hrs.)	53·4 lbs.

Coal per unit (kw. hour) = 1·84 lbs.
Fuel used—anthracite peas at 26/3 per ton.
∴ Cost per unit at switchboard = ·257 pence.

Various Tests.—We have the series of tests carried out in 1905 by the Highland and Agricultural Society of Scotland. These tests on suction producer plants were made so that the great usefulness of the producer might be shown to members of the Society. Each firm was asked to supply two separate plants. Only two men were permitted to attend a plant, and Scotch anthracite at 9s. 3d. per ton was used. There were no serious failures, and but little attention was required. All the producers ran through the ten-hour test. Taking the result of the trials, we find that of the whole tests of six large and four small producers the average coal consumption was one pound per B.H.P., or, say, 20 B.H.P. for one penny per hour. The trials made were on the engines and producers combined, which, after all, was of great service to those who wished to buy complete plants. We shall obtain better results probably from the trials now taking place, but these are enough to show us that the cost of running combined plants is low. From the figures given, it seems that suction producers of from 20 to 25 B.H.P. cost £4 per B.H.P., and smaller producer of about 10 B.H.P. size cost £5 to £6 per B.H.P.

Messrs Crossley, on one of their plants, have reached the very low figure of ·62 lb. of coal per B.H.P. hour. This test, of course, was carried out at their own works and under the most favourable conditions, but they claim for this plant a consumption of ·75 lb. of anthracite per B.H.P. hour when working at full power under ordinary conditions. This, for anthracite at 25s. per ton, represents a fuel cost of ·1d. per B.H.P. hour.

The same makers guarantee a coke consumption of not more than $1\frac{1}{10}$ lbs. per B.H.P. hour for a plant of about 15 B.H.P. capacity.

From the Royal Agricultural Society's trials before mentioned, the following conclusions respecting the fuel and water consumptions when working continuously at the loads specified and under the best conditions were drawn by the judges:—

When using Anthracite:

Full load—1·1 lbs. per B.H.P. hour, including fuel for starting and banking during the night.

Half load—1·6 lbs. per B.H.P. hour, including coal for starting.

Water—1 gall. per B.H.P. hour at full load and ¾ gall. at half load.

When using Coke:

Full load—1·3 lbs. coke per B.H.P. hour including fuel needed for starting.

Water 1½ galls. per B.H.P. hour at full load.

Relative Fuel Cost on Different Types of Internal Combustion Engines.—With a view to enable a ready comparison to be made between the fuel cost of working on different types of internal combustion engines, Messrs Tangye have plotted a number of curves at two rates of fuel consumption in which the ordinates denote the price of the fuel, such as coal per ton, petroleum per gallon, etc., and the abscissæ, the number of B.H.P. to be obtained for one penny per hour.

By a glance at the curves, it will be seen what the fuel cost of an oil engine must be to give the same number of B.H.P. for one penny per hour, to be obtained, say, with a "suction" gas engine at either of the fuel rates of consumption given.

For example:—A "suction" gas engine using coal at the rate of ·8 lb. per B.H.P. per hour, with coal at 25s. per ton, gives 9·3 B.H.P. for one penny per hour.

To equal this, the oil engine, working at the rate of ¾ pint of petroleum per B.H.P. per hour, must use oil costing 1d. per gallon.

The "Town" gas engine, with a consumption of 16½ cubic feet per B.H.P. per hour, must work with gas at 6½d. per 1000 cubic feet, and so on for the other costs of fuels.

Again, the fuel costs may be compared in another way. Taking the engines at the above-mentioned rates of fuel consumption:—

The oil engine at 6d. per gallon gives 1·8 B.H.P. for one penny per hour.

The "Town" gas engine, with gas at 1s. 6d. per 1000 cubic feet, gives 3·3 B.H.P. for one penny per hour, as against the "suction" gas engine giving 9·3 B.H.P. for one penny per hour.

I may mention that the above curves are the copyright of Messrs Tangye, who have kindly given me permission to reproduce them.

The Use of Bituminous Coal.—Up to the present time it cannot be recorded that those individuals who have attempted to design suction gas producers working with bituminous coal have been fully successful. The trouble is with the ash and clinker formed. If this is to be got rid of, a man must be constantly employed at the producer, and then up goes the wages bill, for with bituminous coal, poking is necessary four or five times an hour. With the ordinary suction producers, where only anthracite or coke is used, the sole attention needed is a fresh supply of fuel every two hours.

Some positive mechanism has been used in suction gas producers with this low calorific coal in order to break it up while in the coking stage. One type has a furnace of the underfeed type. Spiral conveyors are used to force the fuel up into the furnace. It is stated that the tar and impurities of the coal mix up with the air from the bottom firebars and are burnt as they pass through the incandescent coal.

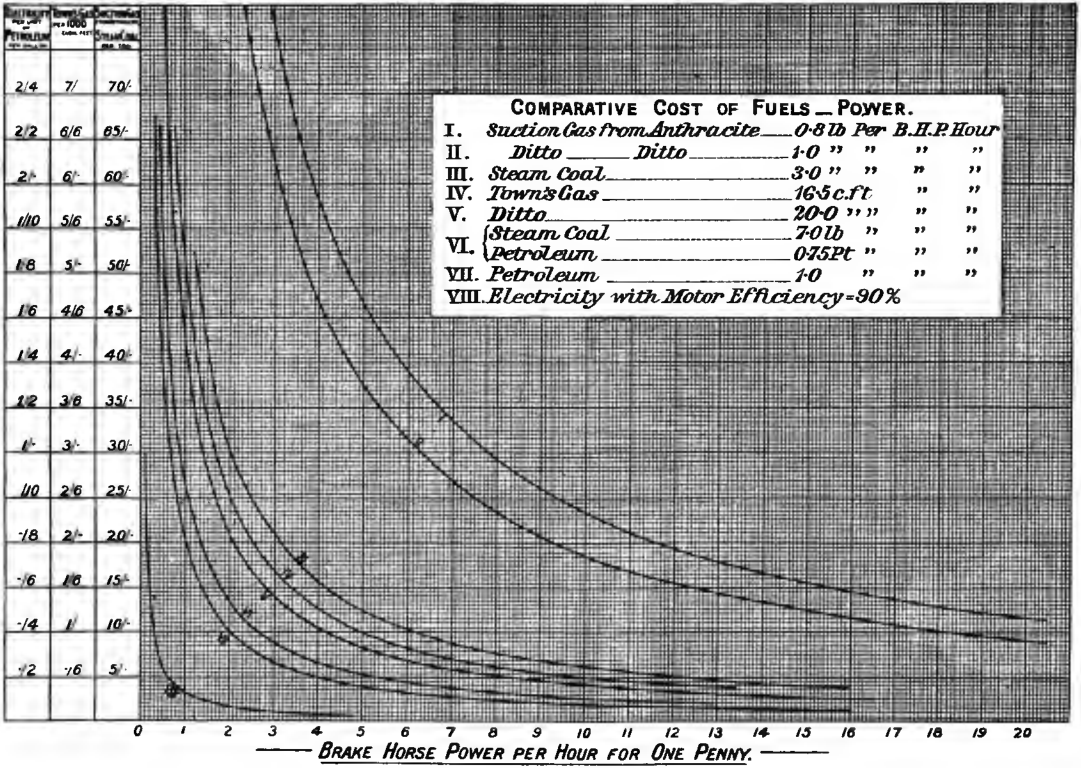


FIG. 17.—Comparative Cost of Fuels for Motive Power.

(No capital, attendance, or other charges are included.)

It is certain that, whether the coal be delivered above or below the surface, a mechanical device must be used to prevent clinkering. It may be possible to economically treat low grade coal to remove the tar, etc., and so have a material—a sort of bye-product—ready for use in the producer.

Tar in Gas.—An even greater difficulty for our manufacturer who wishes to put in a plant of about 40 B.H.P. to drive his engine is the tar which is contained in the gas given off by bituminous coal. This subject of the removal of tar is one which has cost the makers of pressure plants a great deal of trouble. As they are giving it such close attention, it may be that they will devise some method by which it can be removed, even from a suction gas producer.

As we have seen before, it is impossible to include in a suction plant the elaborate cleaning and washing devices that are commonly used in pressure plants, both because of the additional resistance introduced in the path of the gas and from motives of cost. The additional cost of these cleaning towers and washers is not such a serious consideration where large powers are needed, but with the small powers for which suction plants are generally employed, the additional capital, cost, and space occupied render their use impracticable.

The suction producer which works with semi-bituminous coal on the Continent is devised so that the tarry vapours may come through the incandescent zone, but this is not very satisfactory. Mr Dowson appears to be devoting his great experience and ability to this matter, but up to the present, in this country, it is not within the range of practical engineering science. While we can obtain gas coke at somewhere under 15s. per ton it is not probable that bituminous coal will be used for small plants; and where large plants are needed, the possibility of ammonia recovery will make manufacturers inclined to use Mond or other pressure producers. There seems to be no reason why the bituminous coal should not be treated at the pit's mouth as to form coke, which would provide a smokeless fuel, containing no tar, and suitable alike for the domestic fire and suction gas producers. For a description of the generator for use with bituminous fuel, see under "Special Plants."

LECTURE II.

APPLICATIONS AND USES OF THE SUCTION PLANT.

Use of the Suction Plant for Pumping Work.—Gas engines in combination with "suction" gas producers are admirably adapted for the purpose of driving pumping installations.

At a small waterworks at Welwyn (Herts) the duty per cwt. of Welsh anthracite equalled 102,537,000 ft.-lbs. This is a remarkable result, considering that the pump H.P. was less than 2.

This installation consists of two sets of treble-barrel deep well pumps, 4½ in. diameter by 12 in. stroke, 6 B.H.P. Gas engines and "suction" producers, each set being designed to deliver 3000 gallons per hour from a well 60 ft. deep to a reservoir 100 ft. above the surface of the water in the well. The total "head," including friction in the main, equals 120 ft.

At the completion of the contract the machinery was subjected to a ten hours' test by an independent engineer, and the particulars are as follows:—

Each set of pumps delivered 3128 gallons per hour.
Total head 120 ft.
Pump H.P. 1·89
Welsh anthracite beans in 10 hours, 41 lbs.
,, ,, per hour, 4·1 lbs.
,, ,, per pump H.P. 2·17 lbs.
Cost of coal at 20s. per ton per pump H.P., ·233d.
Cost of coal at 20s. per ton to pump 1000 gallons, ·141d.
Duty per cwt. of Welsh anthracite equals 102,537,000 ft.-lbs.

On a larger installation at the East Kent District Water Co., Snodland, Kent, a duty of over 170,000,000 ft.-lbs. per cwt. of Welsh anthracite was obtained.

The installation comprises one set of treble-barrel deep well pumps 7-in. diameter by 18-in. stroke, to deliver 10,600 gallons per hour to the surface from a well 250 ft. deep; and one horizontal treble ram surface pump, 6-in. diameter by 9-in. stroke, to lift 7500 gallons per hour against a total head of 330 ft. The pumps are driven by two 29 B.H.P. gas engines in combination with "suction" producers. The following are the results of tests recently carried out in connection with this plant:—

Well Pump.

Quantity pumped in 9 hours	95,380 gallons.
Quantity pumped in 1 hour	10,597 ,,
Total head pumped against	255 ft.
Pump H.P.	13·64
Coal used in 9 hours	160 lbs.
Coal used per pump H.P. per hour . .	1·3 ,,
Cost of coal at 20s. per ton per pump H.P. per hour	·139d.
,, ,, 27s. 6d. ,, ,, ,,	·191d.
Duty per cwt. of Welsh anthracite . .	170,253,000 ft.-lbs.

Surface Pump.

Quantity pumped in 9 hours	70,000 gallons.
Quantity pumped in 1 hour	7,777 ,,
Total head against	330 ft.
Pump H.P.	12·96
Coal used in 9 hours	150 lbs.
Coal used per pump H.P. per hour . .	1·28 lbs.
Cost of coal at 20s. per ton per pump H.P. per hour,	·136d.
,, ,, 27s. 6d. ,, ,, ,,	·188d.
Duty per cwt. of Welsh anthracite . .	172,480,000 ft.-lbs.

On a still larger pumping installation at Stourbridge Waterworks, where again "suction" gas is employed as the motive power, a duty of 216,000,000 ft.-lbs. per cwt. of anthracite was obtained.

On another pumping installation at Paris-Plage Waterworks, Etaples (France), the fuel used is gas coke.

The plant consists of two sets of treble-ram deep well pumps, 10-in. diameter by 18-in. stroke, driven by two 39 B.H.P. gas engines and "suction" producers. Either pump can be driven from either of the engines. One set was recently tested for a period of five hours and the results are as follows :—

Quantity of water pumped into reservoir in 5 hours	96,400 gallons.
Plus water used for engine and plant	1,100 ,,
	97,500 gallons.

Total quantity pumped per hour		19,500 gallons.
Total head		137·6 ft.
Pump H.P.		13·9
Gas coke used in 5 hours	128 lbs.	
Less cinders	11·2 ,,	
		116·8 lbs.

Duty per cwt. of gas coke (and allowing for partly consumed fuel in generators)	117,000,000 ft.-lbs.
Duty per cwt. of gas coke (deducting cinders)	128,500,000 ,,

Messrs Crossley publish the following results obtained by tests on their plants in connection with pumping installations.

At the Tendring Hundred Waterworks, a 24 hours' combined duty test on a Crossley suction plant, engine and force pumps, gave the following results :—

Average explosion per minute, 55·4.
B.H.P., 76·5.
Water H.P., 62·0.
Gallons pumped per hour, 30,183.
Total head, 402 ft.
Consumption of anthracite, ·664 lb. per B.H.P.
Consumption of anthracite, ·814 lb. per water H.P.
Cost per B.H.P. hour = ·109d.
Cost per water H.P. = ·135d.

In 24 hours, therefore, 724,410 gallons were raised through 400 ft. with a coal consumption of 1223 lbs.

On the cost of anthracite taken above (31s. per ton), we get the result that 1000 gallons were lifted through 100 ft. for ·07 of a penny.

A further test with a Crossley plant was carried out at the Woodmansterne pumping station, Surrey. An 18 hours' test was carried out both with the low level well pumps and the high level force pumps. The results were as follows:—

Low Level Well Pumps.

Average explosions per min.	42·5.
Pump H.P.	56·17.
Gallons pumped per hour	52,162.
Coal per hour	36 lbs.
Cost of coal	5·5 pence per hour.
Pump revs. per min.	14·7.

In this trial 1000 gallons were pumped through 100 ft. for ·07d.

High Level Force Pumps.

Average explosions per min.	53·5
Pump revs. per min.	39·45
Pump H.P.	82·3
Gallons pumped per hour	50886
Coal used per hour	52·21 lbs.
Cost of coal	8d. per hour.

Here 1000 gallons were raised 100 feet for ·0628d.

Gas Producers for Marine Work.—We now come to a further development in the use of suction gas producers which, though not as yet extensively put into practice, seems to open for such plants a wide field of utility.

I think Mr Dugald Clerk was the first authority to prophesy that the gas producer within the first quarter of the twentieth century would take up a primary position in marine work. He made the statement at the 1906 dinner of the Junior Institution of Engineers. One result of his remarks appears to have been that a number of writers have since enlarged upon the possibilities of the subject, but at present the matter has scarcely advanced beyond the discussion stage. Until now the internal combustion engine has only found a place as a means of generating electrical current for lighting ships, and has not assumed a serious position for actual propulsion work. There are obvious advantages, a few of which it may be interesting to recapitulate. Owing to the greater heat economy of the gas producer and gas engine over the steam boiler and engine, the ship would have a greater radius of action, and there would be no need for funnels. Those who have been to sea with bad coal will see some advantage in getting rid of the smoke. The number of stokers would probably be reduced. The marine engineer would experience less difficulty in making joints, and we should be rid of such auxiliaries as feed and air pumps, condensers, etc. The steady load of a cargo vessel is just the sort of thing for an engine to work at its best with, but the great trouble would be the cleaning of the gas producer, as this takes up a good deal of space.

There are also difficulties connected with the engine, that of reversing being one, although, as the steam turbine has shown, this is not an insuperable trouble.

Mr A. Vennell Coster, M. Inst. Mech. E., has, with great ingenuity, compiled some exceedingly interesting facts on this subject. In one case he refers to the fact that "the many famous engineering firms now strenuously engaged in the development of marine gas propulsion recognise that theory in connection with all maritime matters must go hand in hand with practice." Naturally enough, perhaps, great reticence is being shown by the firms so engaged. The main argument in favour of the gas engine is its greater thermal efficiency. The figures available are for plants which develop their power from bituminous coal.

If we summarise the advantages which Mr Coster[1] claims for gas propulsion we find them as follows :—

(I) The vessel may be driven the same distance with half the amount of fuel, or the radius of action is increased 100 per cent.

---

[1] *Cassier's Magazine*, Gas Power number, 1907.

(2) Stand-by losses reduced over 75 per cent.

(3) Reduced racing in a heavy seaway, due to smaller and more deeply immersed propellers.

(4) Having two or more propellers (on similar lines to steam-turbine-driven vessels); less liability to stoppage at sea, and greater handiness when entering port or in narrow waters, as the ship can be steered by the propellers when it has insufficient way on to be controlled by the rudder.

(5) Working pressure confined to the engine cylinders, the gas producers working under atmospheric pressure.

(6) Easy firing and stoking; the gas producers may be charged only twice every twenty-fours, the rolling and pitching of the vessel being rather an advantage than otherwise in assisting the fuel down from the charging hoppers.

(7) The gas producer makes its own steam at about atmospheric pressure; no steam pressure boilers with the following serious and constant disadvantages are required :—

- (*a*) Priming of boilers and water hammer in steam pipes.
- (*b*) Bursting of boiler tubes and steam pipes and joints, the collapse of furnace crowns.
- (*c*) Corrosion and pitting of boilers, due to engine oil forming acids in the condenser which are deposited in the boiler by the return hot feed-water.

  It is acknowledged that the weak place of every steam installation is the boiler; this, in the gas plant, is entirely eliminated.

(8) No condenser and maintenance of a good working vacuum necessary.

(9) Reduction of weight and space occupied by gas engines and producers as compared with steam engines and boilers.

(10) Less auxiliary running machinery required, and fewer pipes and joints to keep tight.

(11) Cleaner ship, because no smoke and less handling of coal.

Regarding the other side of the question, the chief difficulties are :—

(1) The construction of a simple gas producer of the suction type, able to make good gas from bituminous fuel, having fluctua-

tions of calorific value within certain limits; entirely free from tar or dust, and designed to generate gas continuously.

(2) The provision of a system of ventilation to prevent gas leakage into the vessel, with consequent dangers of asphyxiation.

(3) The maintenance of perfect control of the gas-propelled vessel in starting, stopping, reversing, and running at all speeds.

The subject has also been ably discussed in a recent leading article of *Engineering*,[1] in which the following points are brought forward:—

Advantages:—

(1) A saving of one-third in space occupied by machinery and a reduction of one-fourth in the weight of machinery.

(2) As the thermal efficiency of a gas plant is about double that of a steam plant, it should be possible to get 1 H.P. at the propeller for an expenditure of 1 lb. of coal.

(3) A cheaper grade of coal can be used in the producer than would be possible in a boiler. Thus the fuel cost of transport per ton-mile is considerably reduced.

(4) A gas producer will run for several hours without attention, and therefore the large force of stokers necessary with a steam plant would not be required.

(5) Less than one-quarter of the amount of ashes, and therefore the labour of handling much reduced.

(6) No smoke, and consequently the wind resistance of large funnels done away with. Also the space at present needed by uptakes would be saved. This point is of considerable value in naval tactics, as it enables a vessel to get into range before its presence is detected.

The disadvantages considered are all connected with the engine, so that it is not necessary to recapitulate these in the present lectures.

To show that our leading firms are paying very great attention to the subject of producers at sea, the paper of Mr James M'Kechnie before the Institution of Naval Architects may be quoted. He says that at Messrs Vickers, Sons and Maxim's works there have been built internal combustion marine engines of a power equivalent to about 40,000 I.H.P. after three or four years' continuous research work. The gas engine used may be worked either by producer gas, or heavy oil, or compressed air. The change over from gas to oil may be made almost instantaneously. With oil, but little time is lost in starting. In large ships, coal for the producers may be stored in the bunkers and oil in the double bottoms.

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[1] July 3, 1908.

Messrs Thornycroft have done pioneer work in this direction. They have made comparative tests with two vessels, one with a suction gas plant and the other with a steam triple-expansion engine. They find that with equal pull in the towing meter the fuel economy of the suction gas to steam was 1 to 3·44 in favour of gas.

Messrs Beardmore have also been experimenting in this matter, but have not yet built engines for sale. They have constructed a 500 H.P. plant which has been fitted to a gunboat, and has, so they inform me, given great satisfaction and encouragement to go further into the business.

Messrs Crossley are constructing a number of marine sets of various sizes, and have a barge running on the English canals in everyday work.

The plants that have, up to the present, been used in marine work are quite small; but then, the turbine of 1897 was small as compared with those of the "Lusitania" and "Mauretania" of the present day.

The Mersey Gas Producer Company have made a plant of 200 B.H.P. for marine work, with washers suitably shaped to the side of the vessel. This results, of course, in a saving of space.

The illustration shown here of the standard general arrangement of a marine type producer enables one to see the manner in which the Power Gas Co. are designing the Mersey plant (fig. 18).

They do not advise the use of rotary washers when anthracite fuel is used, as they state that stationary scrubbers are quite as efficient, and are more reliable than the former type. Their work in this department is, however, quite in the experimental stage at present.

The leading firms of foreign countries are also paying a good deal of attention to this important innovation.

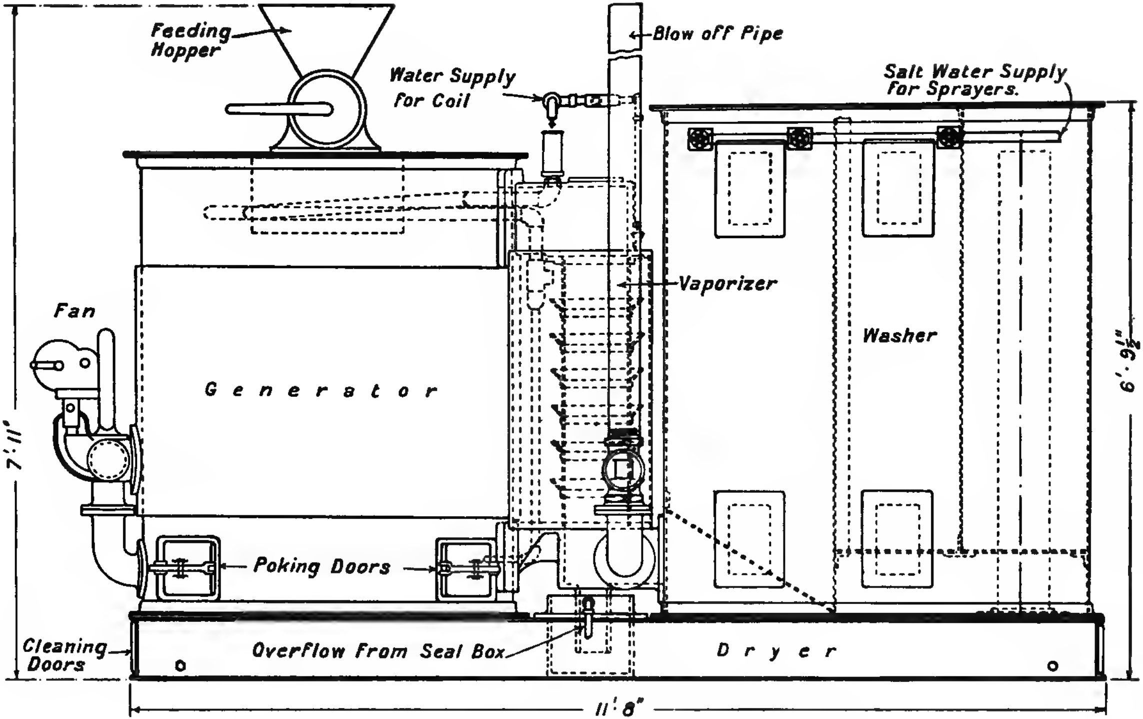

FIG. 18.—Marine Type Producer Standard General Arrangement.

In the course of a conversation which I have had with Mr Flurschein, I learned that Messrs Pintsch are at present making a 250 H.P. suction gas plant to be used on torpedo boats for the German navy. It may be mentioned that this is to be used with a marine engine having 18 cylinders on the one crankshaft. The gas engine weighs 8 lbs. per H.P., and runs at considerably over 1000 revolutions per minute. It is very difficult indeed to obtain definite data from firms engaged on this class of work. One is, at first, rather led to believe that many of them are comforting themselves with pious hopes rather than obtaining actual figures. But this is not quite the true state of affairs. When we find people like Mr Thornycroft, Mr M'Kechnie, Professor Capper, and others publicly giving the opinion "that many of us will live to see the reciprocating steam engine an archaic machine," it is clear that the whole matter has been taken very seriously.

In response to the many inquiries that I have made concerning the attitude of the Board of Trade with regard to the suction gas producers, I have been informed that it is considered very probable that there may be important developments ultimately in this branch of engineering.

There are many small boats carrying passengers which are fitted with petrol motors, and the size of the oil-motor driven vessels is now increasing. There is not a great gap between oil and suction gas; and although the Board have not yet been approached by anyone with a proposal to use suction gas engines on passenger vessels, I am informed that the proposal would be sympathetically received and carefully considered by the department.

In conclusion, however, it may be said that the whole matter is still very much in the experimental stage, and there remains a great deal of work to be done in this direction before any very satisfactory conclusions can be arrived at.

Other uses of the "Suction" Producer.—Besides its use as an agent for motive power, "suction" gas is now being extensively adopted for many kinds of heating purposes where "town" gas has been previously utilised.

The equipment of the apparatus when engaged to perform this class of work necessitates the additions of an exhausting fan and a small gas holder.

The fan draws off the gas from the scrubber, and delivers it into the gas holder, which automatically controls its own filling according to the demands made on it, maintaining at the same time uniformity of pressure of the gas, which is requisite for its successful employment.

In the heating of lacquering stoves, muffles, laundry work, brazing, etc., "suction" gas is rapidly taking the place of "town" gas, owing to the economy to be obtained and the small outlay involved.

It is also used for roasting cocoa, coffee, and other food products, and also for general cooking purposes. One great advantage of roasting and cooking by gas, as compared with a coke fire, is that the heat can be better and more easily regulated. It is especially useful when the operation is one of great nicety. In this connection it is well to consider whether any harmful effect is produced by the contact of the products of combustion with the food. It has been well established that no harmful effects are produced when town gas is used for this purpose. The products of combustion of producer gas are similar to those of town gas (viz. nitrogen, CO_2, and water vapour), and so cannot do any more harm than those of the latter. Provided that the coal from which the gas is made does not contain more than ·5 per cent. of sulphur, there will be no more sulphur compounds in "suction" gas than in town gas.

For heating work generally, it is found that about four volumes of suction gas are equivalent to one of town gas, but for blowpipes and other cases where intense heat is needed it is advisable to allow rather more.

WORKING THE PLANTS.

General hints.—It is natural that the reader will expect to find included in the lectures something about keeping the producers in good working order.

Every engineer approaches a piece of machinery with that spirit of profound caution—at times dangerously akin to distrust

—for which only knowledge and education can be responsible. It is highly probable that a labourer who knows nothing about machinery at all would more cheerfully tackle the duties of looking after a suction gas plant than a man who has had charge of a steam boiler and engine. "Fools rush in where angels fear to tread." It is the same in human affairs. The savages of South America saluted the stranger white man as a god. We, when we meet the white man as a stranger, are rather apt to regard him with suspicion.

We have had the opportunity of examining the plant in detail. We will now see how it should be worked to keep it running at a maximum efficiency.

The Generator.—The grate and the ashpit must be cleaned at intervals during the running of the plant. In addition, the generator should be entirely emptied about once a week in order that the clinkers may be completely removed. Some clinker will almost certainly adhere to the lining, and if permitted to grow in volume will cause trouble.

It is well to take the opportunity to be sure that the doors of the combustion chamber are tight.

The Vaporiser should be examined at this time. Naturally, the way in which the vaporiser behaves will guide the attendant after a time, but until he has had a little experience it is well to watch matters closely. The behaviour of the vaporiser depends to some extent upon the kind of fuel used and the quality of the water employed.

Most trouble will be experienced with plants in which poor quality fuel is used. If it is of a bituminous nature, there is trouble from tar deposits. In this connection it may be mentioned that the connection between the vaporiser and scrubber suffer from obstruction caused by the deposit of tar carried by the gas.

The Washer.—The pipes leading to the washer have been known to clog because of deposits from the gas. Also the lower part of the washer catches, as it were, most of the dust in the gas. This part of the washer can easily be cleaned, and should be looked to about once a month.

It is a mistake to pack the coke or other purifying material too closely together in the washers. Resistance to the free passage of the gas through the washer gives more work to the engine. It is advisable to see that all drain cocks are kept clear. The use of a piece of wire to clear them is obvious.

Makers' Instructions.—There are, of course, certain peculiar duties for various plants. But the makers always issue instructions, and they seem very willing to give advice in order to keep the plants working efficiently. Indeed there are few branches of engineering in which such enterprise has been shown in this matter as by makers of suction gas plants. It is astonishing that, despite the fact that comparatively little independent literature on the subject appeared until the Derby trials of 1906, yet a very large aggregate H.P. of these plants has rapidly been set to work. When one remembers the early days of the evolution of the motor car, then, by comparison, the progress is still more wonderful.

Starting the Plant.—It may be convenient to divide the operations of starting under two heads. There is (*a*) starting the generator, (*b*) starting the engine.

(*a*) **Starting up the Producer.**—The usual practice in lighting the fire is as follows:—As a basis, use a piece of oil waste, and cover this with some wood shavings. Over shavings place some short sticks of wood and then a bucketful of coal—then another layer of sticks and coal. The fire should then be lighted after opening the vent pipe. After the wood is well alight the fan should be started, and herein one of the disadvantages of the suction plant lies. Before a burnable gas is obtained, the fan has usually to be turned for about fifteen minutes. This defect could to a great extent be overcome if more attention were paid to the vent pipe. In most plants the pipe is not nearly tall enough. Vent pipes should not be less than 30 ft. high and 3 to 4 ins. in diameter. Sharp bends should be avoided, as they favour the deposit of soot, and, for the same reason, there should be no long horizontal lengths of pipe. With such a chimney the fan would only have to be used as an auxiliary draught producer, a continuous stream of air from the fan being unnecessary. The fan is often used to blow the air through the producer instead of sucking it through. This has the advantage that, the inside of the producer being under pressure, any leakage can be detected

—for which only knowledge and education can be responsible. It is highly probable that a labourer who knows nothing about machinery at all would more cheerfully tackle the duties of looking after a suction gas plant than a man who has had charge of a steam boiler and engine. "Fools rush in where angels fear to tread." It is the same in human affairs. The savages of South America saluted the stranger white man as a god. We, when we meet the white man as a stranger, are rather apt to regard him with suspicion.

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The Generator.—The grate and the ashpit must be cleaned at intervals during the running of the plant. In addition, the generator should be entirely emptied about once a week in order that the clinkers may be completely removed. Some clinker will almost certainly adhere to the lining, and if permitted to grow in volume will cause trouble.

It is well to take the opportunity to be sure that the doors of the combustion chamber are tight.

The Vaporiser should be examined at this time. Naturally, the way in which the vaporiser behaves will guide the attendant after a time, but until he has had a little experience it is well to watch matters closely. The behaviour of the vaporiser depends to some extent upon the kind of fuel used and the quality of the water employed.

Most trouble will be experienced with plants in which poor quality fuel is used. If it is of a bituminous nature, there is trouble from tar deposits. In this connection it may be mentioned that the connection between the vaporiser and scrubber suffer from obstruction caused by the deposit of tar carried by the gas.

The Washer.—The pipes leading to the washer have been known to clog because of deposits from the gas. Also the lower part of the washer catches, as it were, most of the dust in the gas. This part of the washer can easily be cleaned, and should be looked to about once a month.

It is a mistake to pack the coke or other purifying material too closely together in the washers. Resistance to the free passage of the gas through the washer gives more work to the engine. It is advisable to see that all drain cocks are kept clear. The use of a piece of wire to clear them is obvious.

Makers' Instructions.—There are, of course, certain peculiar duties for various plants. But the makers always issue instructions, and they seem very willing to give advice in order to keep the plants working efficiently. Indeed there are few branches of engineering in which such enterprise has been shown in this matter as by makers of suction gas plants. It is astonishing that, despite the fact that comparatively little independent literature on the subject appeared until the Derby trials of 1906, yet a very large aggregate H.P. of these plants has rapidly been set to work. When one remembers the early days of the evolution of the motor car, then, by comparison, the progress is still more wonderful.

Starting the Plant.—It may be convenient to divide the operations of starting under two heads. There is (*a*) starting the generator, (*b*) starting the engine.

(*a*) **Starting up the Producer.**—The usual practice in lighting the fire is as follows:—As a basis, use a piece of oil waste, and cover this with some wood shavings. Over shavings place some short sticks of wood and then a bucketful of coal—then another layer of sticks and coal. The fire should then be lighted after opening the vent pipe. After the wood is well alight the fan should be started, and herein one of the disadvantages of the suction plant lies. Before a burnable gas is obtained, the fan has usually to be turned for about fifteen minutes. This defect could to a great extent be overcome if more attention were paid to the vent pipe. In most plants the pipe is not nearly tall enough. Vent pipes should not be less than 30 ft. high and 3 to 4 ins. in diameter. Sharp bends should be avoided, as they favour the deposit of soot, and, for the same reason, there should be no long horizontal lengths of pipe. With such a chimney the fan would only have to be used as an auxiliary draught producer, a continuous stream of air from the fan being unnecessary. The fan is often used to blow the air through the producer instead of sucking it through. This has the advantage that, the inside of the producer being under pressure, any leakage can be detected producer should on no account be filled full of fuel up to the hopper door, because there is then a liability of the gas outlet becoming choked, and of the proper production of gas being thus interfered with.

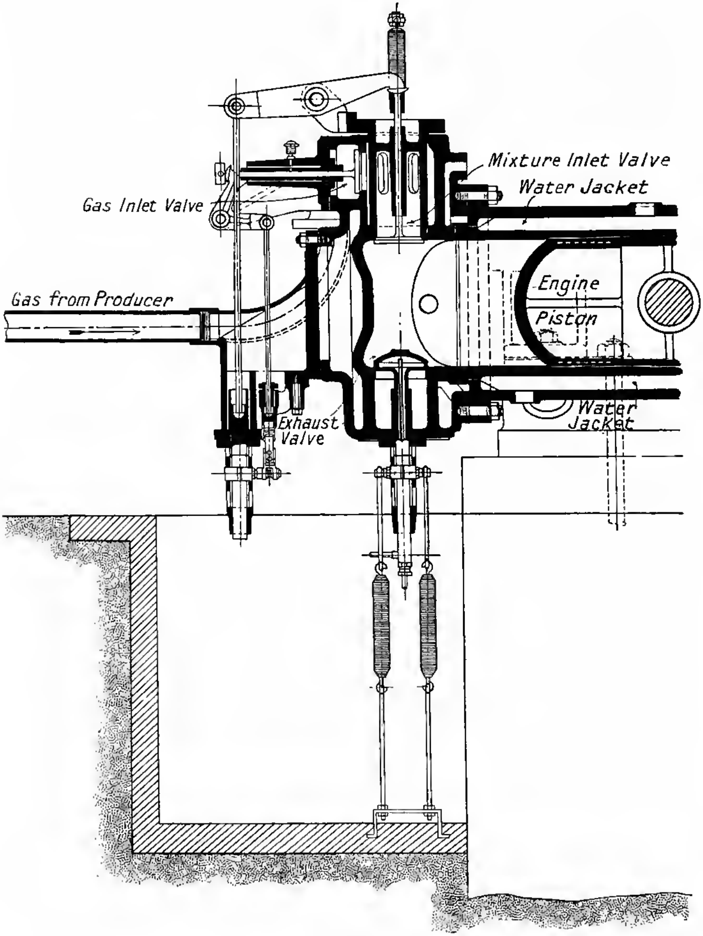

FIG. 19.—Gas Engine Valve Mechanism.

The top layer of coal should never be allowed to become incandescent; this point can be watched through the sight hole if such is provided.

When the coal in the producer burns through so that the top layer is incandescent, fresh fuel should be added, and this, under normal conditions of working, is a general guide to the stoker as to when fuel is required. If, however, air is leaking past the firebrick lining into the top of the producer, as described above, the top layer of coal will burn before it ought to, and the cure then lies in making the firebrick lining tight, and not, of course, in adding fuel. On the other hand, if an insufficient amount of steam is passed through the plant the fuel will burn through more quickly, so that it may mean that more steam is required.

The working of the engine is one of the best indications as to how the gas plant is working. If the gas is good, a fewer number of charges will be required to do a certain amount of work than would be needed if the gas were of poor quality, so that by watching the governor of the engine and noting the amount of gas which is taken in, the quality of the gas, and therefore the condition of the fuel in the producer, can be determined.

When the gas begins to fall off in quality, the engine will take an increased number of charges of gas to do the same amount of work; or, with engines of a certain design, a larger quantity of gas will be taken in at each charge. If the gas falls off seriously in quality, the engine will probably slow down. This usually indicates that fresh fuel is required in the producer, so that the fire should be examined through the mica sight hole; or it may indicate that some readjustment of the water supply to the plant or the air supply to the engine is required.

The best adjustment is, of course, that one in which the least quantity of gas is consumed to do the work.

Leakage.—Any leakage of air into the suction plant is extremely detrimental to the quality of the gas produced. If the leakage takes place through defective lining in the producer, combustion of the gas will take place, and, consequently, the gas supplied to the engine will contain a larger percentage of the useless gas CO_2. If leakage takes place at joints, combustion of the gas may not take place, but it will, at any rate, result in impoverishing it.

Too much emphasis cannot be laid upon the great need for good joints in all the pipes connecting the producer to the engine. For the suction gas plant leaks inwards. The joints may to all appearance be perfect, but perhaps air is going in, and the gas is becoming so weakened on this account that the engine cannot be started. Makers say that a very high grade of workmanship is required for these joints, and it is probable that when there has been trouble with the plants just after erection it has been invariably due to these poor joints. This only emphasises the great importance that the job should be done thoroughly.

The usual practice in lining the producers with firebrick is to use ordinary bricks, taking care that joints do not coincide on alternate course. The life of the lining is much increased and the risk of leakage diminished if the layers of bricks are dovetailed into one another.

The Steam Supply.—The importance of an efficient steam supply to the producer cannot be overestimated. In addition to causing clinkering, lack of water vapour impoverishes the gas, due to the loss of the hydrogen, and also involves a larger volume of air to bring about the necessary reactions. In a well-designed producer the air should be long enough in contact with the steam to become completely saturated. The hotter the air is, the greater is the quantity of vapour it can take up, and consequently, within limits, it would be very advantageous to pre-heat the air. This superheating of the air and steam should not be carried to excess, otherwise there would be a danger of burning out the fire-bars. A good way to avoid this danger is to have a small quantity of water in the ashpit. The steam thus generated not only forms a safeguard as regards temperature, but also serves as a temporary supply when the engine draws direct from the atmosphere through the opening of a fire-door.

The regulation of the supply of water to the coke scrubber is also important. If the supply be too small, steam will be formed in the scrubber, the gas will not be efficiently cleaned and cooled, and consequently the power of the engine will fall off. If, on the other hand, the supply is too great, the height of the water seal will be too great, and the engine may not be able to suck the gas through the producer. The supply should be so adjusted that the gas is quite cold when leaving the scrubber. This can be readily tested by placing the hand on the scrubber, when it should feel warm at the inlet and cold at the outlet.

The coke in the scrubber will, generally speaking, be serviceable for a period of nine to twelve months, but this, of course, depends upon the amount of work that the plant is called upon to do.

When the engine is at work the surface of the water in the hydraulic box should be constantly in movement, rising and falling slightly, the movement varying with the amount of gas required by the engine. This movement is usually 1-in. (25 mm.), any movement more than this generally indicating a choking up of the producer, and this should be attended to at the earliest possible moment.

Cleaning.—How frequently the fire will have to be cleaned will depend upon the quality and amount of fuel used; speaking generally, once a day will be sufficient; this is most conveniently done when the engine is stopped at the end of the day. Should it be necessary to stir up the fire whilst the engine is at work, this can be done by means of a poker inserted through a small hole in the ash-door.

If it is necessary to take out the clinker while the engine is at work, this should be done very quickly, so as to allow as little air as possible to enter the gas producer, for should an excess of air be allowed to enter, the gas made would be of inferior quality. It is advisable not to disturb the fuel in the producer more than is necessary whilst the engine is at work.

The gas producer should be cleaned out entirely about once a week, and the clinker then chipped off the firebrick lining if necessary. It should never be cleaned directly after the fire is raked out, but should be allowed to cool down gradually, otherwise the firebrick lining will probably crack, through the rapid change in temperature.

Any dust that settles in the scrubber should be washed out every week by opening the sludge cock and running water through. When the coke is first put into place, this may have to be done more frequently, as new coke often contains a large quantity of dust. The spray pipe at the top of the scrubber should also be examined periodically to see that the holes are all clear and that the water sprays uniformly over the whole surface of the coke, as, if this is not done, the holes are liable to become clogged, and the gas, in consequence, only partially cleaned.

Stopping the Plant.—To stop the plant, the gas cock of the engine should first be shut, and the waste valve in the blow-off pipe opened at once to allow the remaining gas to escape. The steam supply should then be cut off, and the ashpit door opened a few inches to create a draught and allow the fire to continue burning. The valve supplying the evaporator with water should be left dripping, so that the vaporiser is never short of water.

With these general instructions on the working of suction plants, I will now pass on to consider some of the plants actually in use, with the object of showing how theoretical considerations are embodied in the various designs, and how they are modified for practical purposes.

TYPICAL PLANTS.

Bischoff Producer.—Perhaps it will be as well, first of all, to describe a very elementary form of gas producer, as this will clearly show the improvements and modifications that have been introduced into this part of the plant. The first internally fired gas producer was introduced by Bischoff, of the Harz district, in 1839. It works with air only, and consists of a brick structure, with a fire-grate at the bottom, a gas exit at the side, and a chimney through which fuel is fed. The chimney draught draws air through the bottom of the producer, it passes upwards through the fuel, and the gas formed leaves by the opening at the side. This producer is, of course, merely of historical interest, and those readers who wish to trace the historical growth of gas producers in general may consult the paper of Mr F. J. Rowan in vol. lxxxiv. *Proc. Inst. C.E.* (1885). Of course that paper does not say much about suction producers, as it was written before Bénier introduced his first practical plant.

Bénier's first effort.—Some of the earliest producers that were used for furnace work operated on a suction principle, but for many years the pressure producer alone was used.

To Bénier must be given the credit for first using a suction

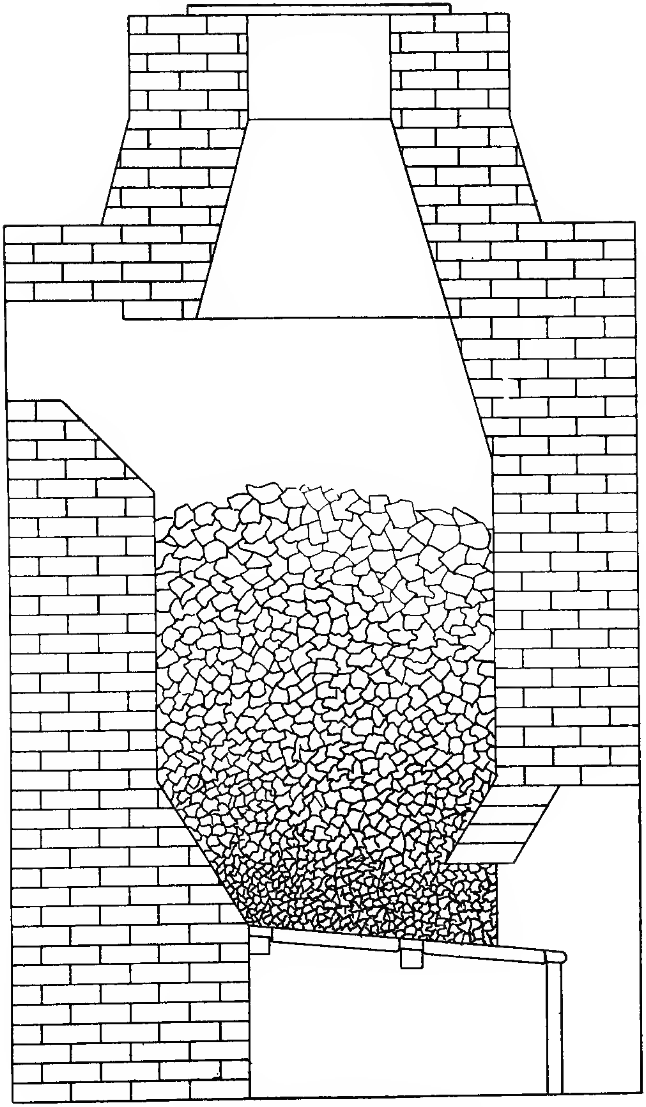

FIG. 20.—Bischoff Gas Producer.

producer with a gas engine using compression. The first suction producer used in practical work is shown in fig. 21. Here we have the gas producer A, into which the coal is fed from the hopper B. The firebrick lining of A is supported by the inner casing Z, which in turn is held in position by an outer shell, leaving an annular space R between the two casings. O is a revolving grate, containing water. The heat from the producer A vaporises some of the water in O. The steam thus formed passes into the chamber P, is then expanded to atmospheric pressure, and enters the mixing chamber E, where it mixes with the air introduced at F. The air and steam then pass down the annular passage R surrounding the inner casing, and in doing so take up some of the heat radiated from Z, and enter the producer A in a more or less heated condition. (This feature is retained in the "Mond" producer.) The gas generated in A passes into an annular chamber T, and from this down the cylinder Q, which contains water, into the inner cylinder Y. The lower end of Y is dipped in the water contained in Q, so that it forms a washer for the gas. There is an overflow pipe from Y to the tank L, so that the water-level in Y is kept constant. From Y the gas passes into a chamber K, which simply serves as a reservoir to contain a small supply of gas, and thence, through the outlet, to the engine. The engine was of the two-cycle type, a pump being used to suck the gas from the producer and to force the charge into the engine cylinder, the exhaust escaping through a ring of ports uncovered by the piston at the end of the working stroke. The presence of this pump, driven from the motor cylinder, gave the engine a bad mechanical efficiency. In fact, when tested by Professor Witz in 1894, one of these plants developed 27·6 I.H.P. on full load, and only 14·59 B.H.P., giving a mechanical efficiency of ·53. The fuel consumption, moreover, was 1·57 lbs. of anthracite per B.H.P., whilst pressure plants at that time were only using 1·1 lbs. per B.H.P. Still, it was a step in the right direction, and it was certainly the birth of the present-day suction plant, which is therefore only fourteen years old. Moreover, the work of Bénier caused many clever inventors to fix their attention on this type of plant, with the result that it was very soon improved. The most notable of these improvements was that

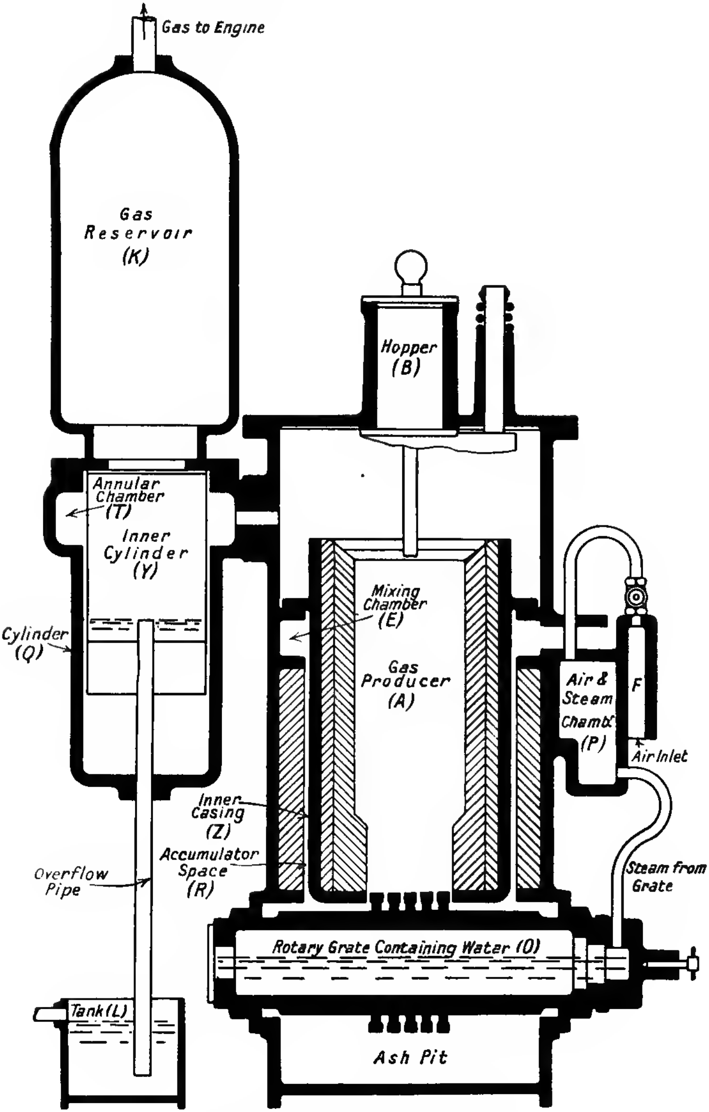

FIG. 21.—Bénier Producer Plant.

which caused the suction stroke of the engine itself to draw the gas from the producer, thus doing away with the suction pump, and considerably increasing the mechanical efficiency of the engine. Since that time there has been no great alteration in principle of the suction producer, the improvements being mainly in the perfection of the various details. I shall therefore pass on at once to the more modern designs, omitting any description of the various plants that come between in the matter of development.

First of all, perhaps, it will be as well to give a brief description of a modern type of "Pressure Plant," in order to show more clearly the fundamental differences in design between the two kinds of plant.

500 B.H.P. Bituminous Coal Gas Plant.—The generator consists of a rectangular riveted steel shell, lined with firebrick, and closed by a water seal at the bottom. The water trough runs across the producer at right angles to an A-shaped grid, which serves both as a grate and as a blast distributor. The blast of air and steam is introduced below this grid at a pressure greater than that of the atmosphere, hence the name "*pressure* plant" as distinct from "*suction* plant," where the pressure is lower than one atmosphere. The steam for this purpose is supplied by an auxiliary boiler. The gas thus generated passes through the gas valve into the atmospheric condensers. The majority of the fine dust present in the gas after leaving the producer is deposited in a box at the foot of the gas outlet pipe, between the generator and the condensers. There are four of the latter: the first two consist of solid riveted steel shells, through which the gas passes at a very low speed, to secure the deposition of any dust that has passed the dust box. The other two are constructed on the annular principle, with the idea of quickly cooling the gas. From the condensers, the gas passes up a coke scrubber, similar to those used in suction plants, which therefore needs no further description. After leaving this, it passes through a "Livesey" washer. This consists of a cast-iron chamber fitted with very finely perforated sheet iron, which is covered with water, and through the perforations of which the gas has to pass. This divides the gas up into minute particles, and effectively washes out the tar and other impurities that may be present. From this washer, the gas passes into a sawdust scrubber. This is provided with trays, in which sawdust or other suitable material is placed in order to take up the moisture carried over from the washer. The gas is then stored up under pressure in a gas holder, from which it may be conveyed to the engines or other appliances in which it is used. This elaborate cleaning and washing plant is not required for suction gas, nor is a gas holder necessary. On the other hand, a more expensive fuel must be used in the latter case, as the gas would otherwise be too dirty for use. It is obvious, therefore, that when much power is needed, a pressure plant is preferable, as the larger size of the plant permits a greater capital expenditure, and the running costs become a more serious item. If, on the other hand, only a small amount of power is required, the capital cost becomes the principal consideration, the cost of fuel being relatively less important, so that a suction plant is generally used.

The first suction plant that I wish to describe is that of the National Gas Engine Co.

The National Plant.—This firm have an installation of suction gas sucessfully at work which aggregates over 3000 H.P. They make it a point of fact, that suction gas is equally economical whether it is in units of 10 B.H.P. or in larger units of 300 H.P. There are in existence many thousands of small factories, and most power users only require an average of about 40 H.P. It is, therefore, this type of plant which is most in demand. In dealing later with the comparative cost of working with electricity, town gas has most to fear from suction gas. Some figures supplied by this firm will be used, as well as others obtained from various sources of information. It will, of course, be only natural for the reader to assume that the figures are obtained from an authority certain to be biassed in favour of suction gas. But I think it fair to state that they appear to be very reasonable, and, after all, every engineer can be covered by obtaining a guarantee, or even requesting an agreement to be drawn out for his own case. Clearly, the cost of coal and the tariff for electricity will affect it in different places.

In all sizes up to 120 B.H.P., the generator of the National plants are constructed in cast iron, and the joints are machined throughout. This secures a sound and durable job, and the makers claim that it is a distinct advantage. They state that although some plants are made entirely of wrought iron for the sake of cheapness, there is a great tendency to corrosion, and this reduces the life of the plant. This is one advantage the engineer gets from close competition. He can be quite sure that rival makers will point out various defects in other plants, and it is for him to judge of the importance of such defects. The construction of generators of cast iron is more costly, but it would appear that the longer life of the plant justifies expense. At the same time, since the ashpan is most affected by corrosion, the result is satisfactory if that is made of cast iron. The vaporiser consists of a ribbed casting surrounding the coal hopper. The hot gas from the fire passing through the annular space between the two, parts with some of its heat to this casting. This ribbed cylinder is surrounded by a second external one which is bolted to the furnace casing and can be removed without disturbing the vaporiser. When hard water only is available for use in these plants, the effective cleaning of the vaporiser becomes an important matter. It may be mentioned that when the external cylinder above referred to is removed, the whole of the vaporiser is immediately exposed. The feed water drips into a funnel, from which it is conveyed to a "Field" tube. This is an arrangement consisting of two concentric tubes, the outer one being closed at the bottom, and the inner one discharging close to the bottom of the outer tube. So that if the water in the outer tube is heated, it rises up that tube, and water descends through the inner tube to take its place. The whole arrangement is fitted inside the outlet pipe which conveys the gases from producer to scrubber, and the feed water is thus preheated at the expense of the sensible heat of the outgoing gases. From this pre-heater, the water is conveyed to an open cup at the top of the vaporiser proper, which, as we have seen, is also heated by the gases leaving the producer. V-shaped notches are cut at intervals along this trough or cup, so that some of the water overflows on to the ribs immediately below. The water spreads horizontally along these ribs; and as these are of different widths, the widest being at the bottom, it must either trickle down the sides or else pass from rib to rib. These hot ribs, therefore, act in the same way as a flash boiler. It is noticeable that this firm makes no attempt to reduce the supply of steam at low loads, though this could easily be done by cutting off the water supply to the pre-heater.

The air is heated on its way to the producer by passing round the pipe through which the gases pass on their way to the scrubber. This pipe has vanes cast on the outside, and a cylinder is fixed round the outside of these. Thus a screw passage is formed between the outside cylinder and the pipe, and the air passes round this passage, so that its temperature is considerably raised by the time it reaches the producer. The furnace is of uniform diameter, the lining being formed of special firebricks, separated from the casing by a thin layer of slag wool to prevent radiation of heat from the producer body. By removing the outside casing of the vaporiser, and the vaporiser casing itself, the firebrick lining is quite easily reached, so that the bricklayer should have no difficulty in making good joints between the various sections of the firebrick.

The charging hopper consists of a cast-iron casing, in the bottom of which a mitre valve is fitted. The latter is operated by an external lever. The use of this type entails rather more air admission on charging the fuel than takes place with some other types, as the hopper cannot be completely filled owing to the necessity of lifting the valve from its seat when charging.

Crossley Plant.—The producer consists of a cylindrical chamber with a firebrick lining, which is separated from the outside metal skin by a layer of sand. This latter serves to keep the heat within the furnace. The firebrick lining rests on a metal ring, supported by two cast-iron, segmental-shaped superheaters, placed in the hottest part of the fire, and mounted on a flat plate right across the producer. This disconnection of the bottom of the firebrick lining and the grate, together with the presence of the metal ring in the hottest part of the fire, serves to minimise, if not to entirely prevent, the formation of clinker on the firebrick. The judges of the R.A.S. trials (1906) state that this contention was fully confirmed, not a vestige of clinker being ever found on the firebrick.

The plate on which the superheaters are supported has a hole in the middle over which the fire-bars are placed. In this way a pit is formed immediately below the fire-grate, and in this pit the steam and air mix before passing to the fire.

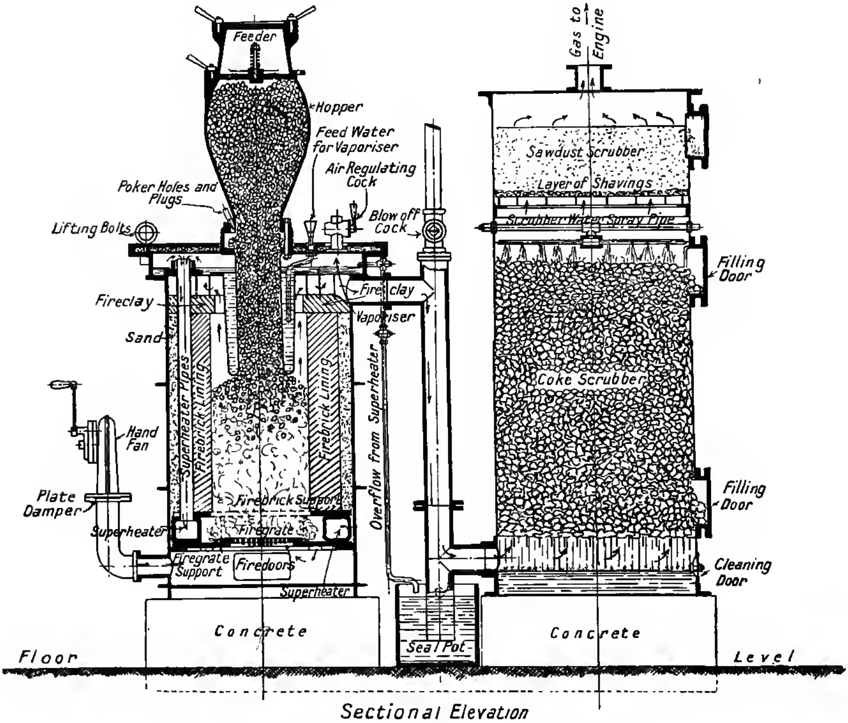

FIG. 22.—Diagrammatic Arrangement of Suction Gas Plant described on pages 85–87.

Around the cylindrical bell defining the depth of fuel in the producer, is formed the "well" of the "saturator" or "vaporiser." Cold water is introduced through a tube to the bottom of this well, and fills the rest of the saturator to a level defined by an overflow pipe. The rest of the vaporiser is shaped like a flat dish, extending to the outside shell of the producer. This dish has a series of baffle plates on its under surface, which form passages through which the hot gas has to pass, giving up its heat to the water before going to the scrubbers. Two vertical pipes form the connection between the vaporiser and superheaters. The vaporiser itself is made of steel, pressed into shape (not riveted), thus reducing the liability of leakage to a minimum. It can easily be removed for cleaning or renewal.

Another feature of this producer is the double air supply. The air inlet for what is called by the makers the "primary air" is placed on the top cover; the air is heated by contact with the hot surfaces, and, after taking up moisture from the vaporiser, passes down the vertical pipes referred to above into the superheaters. There is also a "secondary dry air" supply, which by a throttling action reduces the supply of steam in proportion to the load. In some plants, moreover, an arrangement is made to heat the air and steam by means of the exhaust from the engine. Some heat is recovered in this way, but a greater advantage is due to the fact that the supply of steam to the producer may in this way be varied according to the load. It is obvious that, with such an arrangement, the steam supply will depend upon the number of explosions in the engine, and consequently will follow the variations in the load with very little lag.

The charging hopper is different from that of the "National" producer. It consists of a large fuel chamber, fed from the top by means of a revolving hood, no valve being used. This has the advantage of admitting no air with the coal, but needs a little more care to keep it in easy working order.

The scrubber is of the usual type, but has, in addition, a sawdust scrubber, supported on the top of the coke scrubber. This has, of course, the advantage of cleaning the gas from dust and tar without taking up any more floor space than the original plant, and with a very little increase of capital expenditure. A disadvantage, of course, is the increased resistance included in the path of the gases.

A section of the Crossley plant is shown in fig. 22.

The Campbell Plant.—The producer body is a circular steel casing, consisting of a steel plate riveted together, and fitted with a door at the lower end which opens into the space above the fire-grate. In the plants up to and including 40 B.H.P. only one of these doors is fitted, but for higher powers two are made, one on each side of the casing. The presence of the two doors makes it comparatively easy to clear away ash and clinker in a large plant, as they can be pushed out through one door from the other. A small supplementary door is fixed to the back of the large door to enable the ash to be removed from the top of the fire-bars when

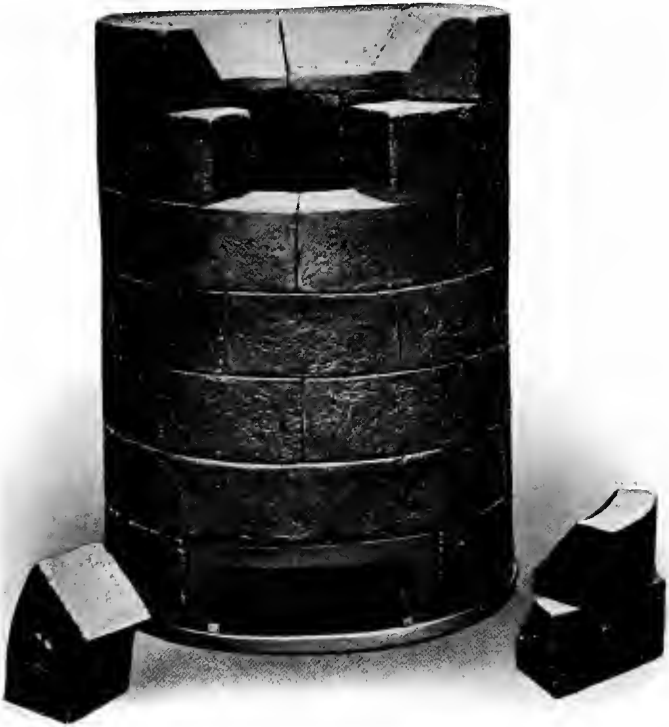

Fig. 23.—Firebrick lining and Grate of the Producer.

the plant is at work. The makers claim that the use of steel plate gives flexibility to the producer body, allowing it to expand and contract readily at will. They state that the fractures that occur in cast-iron bodies are frequently due to the absence of such flexibility.

The body is lined internally with firebricks. A view of this lining is shown in fig. 23, which also shows the fire-grate and bridge-piece round the door opening into the generator at the bottom. This producer has a layer of sand between the firebrick lining and cylindrical body, as in the Crossley producer, and the bottom layer of bricks is well set in fireclay all round, so that all crevices through which air might enter are stopped up.

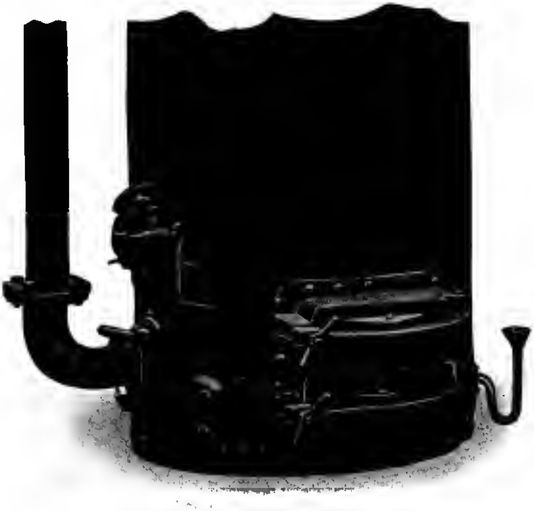

Fig. 24.—Ashpan and Body of the Producer.

The ashpan only is made of cast iron, because the latter offers greater resistance to corrosion than a steel plate. The method sometimes adopted of making the ashpan and generator body in one piece and of steel plate is represented in fig. 24. This is usually only about $\frac{5}{16}$-in. thick; and as water is usually prevalent externally, and absolutely necessary internally, it is seen that this type of construction is very liable to corrosion. A cast-iron ashpan is, on the other hand, usually about ¾-in. thick, and, by its very nature, is less liable to corrosion than steel. When corrosion does take place, so that air is admitted into the generator by any but the right channels, the working of the producer becomes unsatisfactory. A view of the "Campbell" ashpan is shown in fig. 25. Another view of this ashpan, showing the arrangement of the fan for starting up the producer, is shown in fig. 26. The vaporiser of the Campbell plant is fixed directly on top of the generator, and consists of an open-mouthed boiler, somewhat similar to the Crossley pattern. In this case, however, the hot gases pass along a passage formed by the concave bottom of the vaporiser instead of being deflected by baffle plates. The construction is such as to allow full freedom for expansion and contraction. A loose plate is fitted on top of this boiler, so that it can easily be lifted to clean out any deposit left by the water.

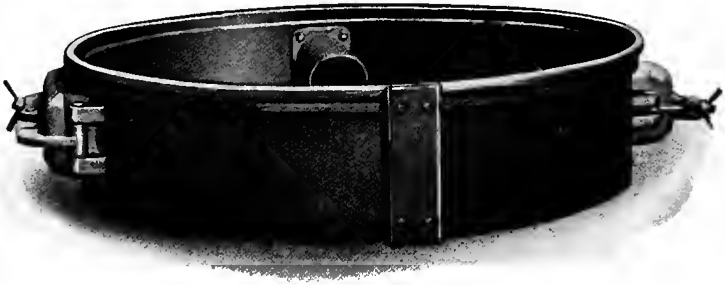

FIG. 25.—Ashpan of the Producer.

The coal hopper is closed by a valve with a weighted lever, and is such that the hopper can be completely filled when charging, so that no air is admitted when charging. This is an improvement on the other type of valve movement, as the valve here opens downwards, with the result mentioned. The upper portion is closed by a hinged plate. A sight hole covered with mica is fitted in the upper plate, so that the condition of the fire can be seen when necessary. Poking holes are also provided in the larger plants, so that if clinkering occurs, these can be used if necessary.

On its way to the scrubber, the gas passes through a simple form of separator, consisting of a large pipe divided lengthways into two parts by a partition reaching almost to the bottom, which is closed by a water seal. The gas is introduced on one side of this partition, passes downwards round the bottom and up the other side of the separator. The heavier particles of dust, however, not being able to change their direction so readily, continue their downward movement and are trapped by the water seal.

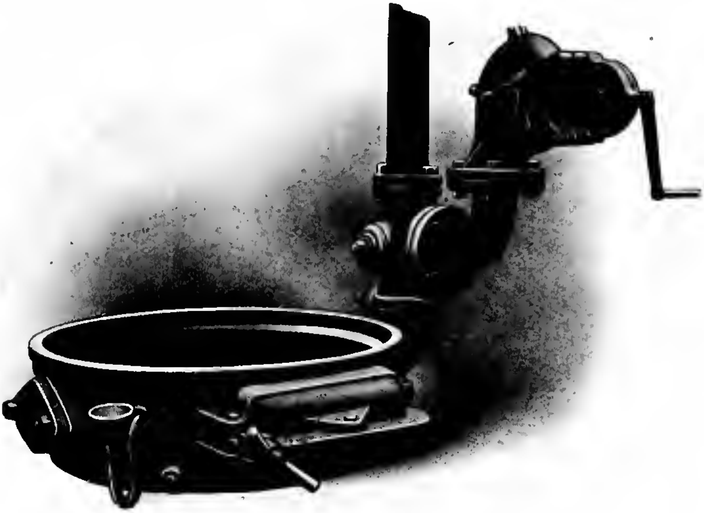

FIG. 26.—Another View of Ashpan, showing the Fan for starting up the Plant.

For plants of 50 B.H.P. and upwards the separator is also arranged to act as a superheater. The gas passes through this superheater, and is made to give up a large proportion of its waste heat to the air and steam on their way from the vaporiser to the fire.

The bottom of the scrubber is itself formed into a water seal, into which the gas pipe dips. The amount of seal required is $\frac{1}{8}$-in. to $\frac{1}{4}$-in. (3 to 6 mm.) according to the size of plant. This can be adjusted by lowering or raising the overflow pipe from the scrubber to the water seal previously mentioned.

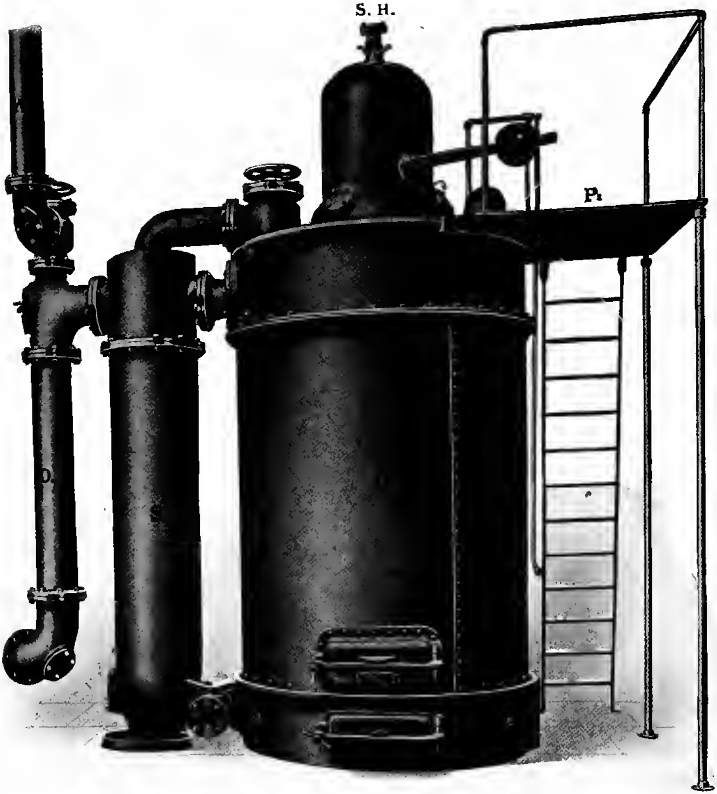

FIG. 27.—Generator of 150 B.H.P. Suction Plant.

The joint between the steel casing of the producer and the cast-iron ashpit is made of soft asbestos pulp or similar material caulked in. That between the producer body and evaporator is of red lead and asbestos cord. The joints on gas piping and doors are all made with asbestos sheeting. Other materials may be used, but must be fire-resisting where they come into contact with gas, and water-resisting if required to withstand water only.

The complete arrangement of a 60 B.H.P. Campbell plant with overall dimensions is shown in fig. 8. A photograph of a 150 B.H.P. plant is given in fig. 27. The various parts are indicated as follows.

G—generator; A—ashpan; V—vaporiser; S—superheater; H—hopper; P—platform; I.P.—inlet pipe to superheater; O.P.—outlet pipe from superheater; S.H.—sight hole in generator; W.P.—waste pipe for gases passing to atmosphere; P.H.—poking holes.

Tangye Plant.—The cylindrical casing and firebrick lining of the producer are much the same as those we have already considered. The lining is held up by a plate, cast in one with the producer body; this plate also supports the firebars. The latter are so spaced as to allow the ashes to fall through, as their further use in the generator is not required. The ashpit is simply a continuation of the producer body. It is supplied with water overflowing from the vaporiser, which cools the ashes as they fall into it from the fire-grate, and produces steam which helps to enrich the gas. It is therefore important to keep water always in the ashpit, any excess being drained off by means of an overflow pipe. The ashes may be cleared out, say, every four hours. This may be done while the engine is at work, if done quickly. The fuel chamber simply consists of the space between the furnace and the hopper, and acts as a storage for fuel, instead of using a distilling bell, as is done in other plants. The tarry vapours given off from the raw fuel cannot pass directly to the gas outlet, however. They have to travel downwards through the incandescent fuel until they get below the vaporiser before they are able to do so, and by that time they are in great part split up into fixed gases. The fuel hopper is, again, of a different type. This, the charging device, consists of a sliding door at the bottom of the hopper, which is moved by means of a handle from the outside. This is preferable to the types already noted, but must be nicely arranged to work freely, without permitting leakage of air into the furnace. If the fuel chamber has been previously well filled, it is sometimes impossible to prevent coal from jamming between the top and bottom faces of the hopper and the end of the sliding door. Charging slides in general have the advantage over valves, that a poking tool can be inserted right through the generator to the fire-bars, and that all parts

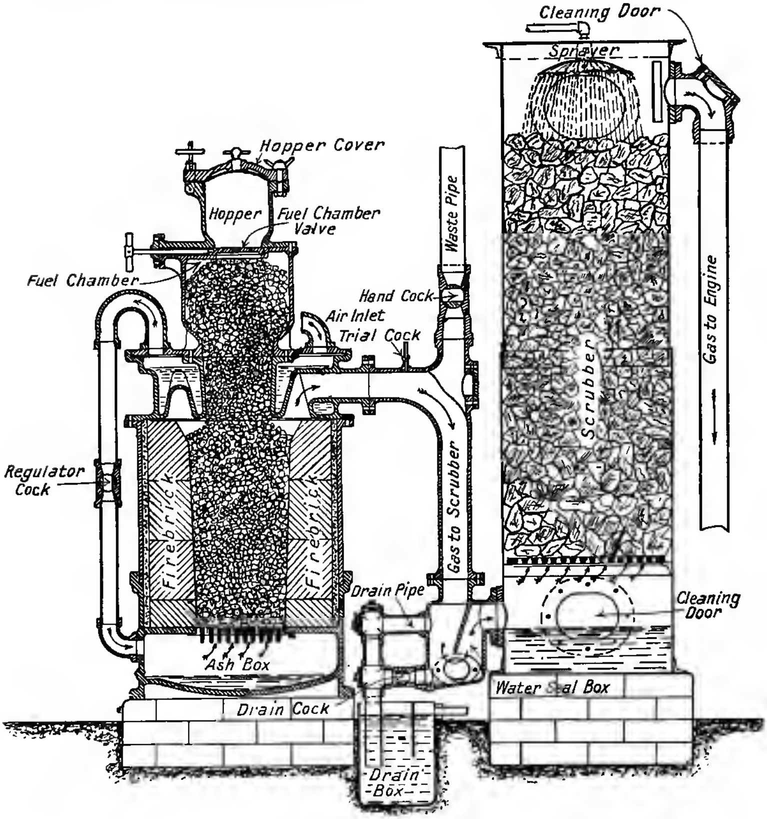

FIG. 28.—Plant with Annular Chamber Type of Vaporiser.

of the producer are then accessible. With a valve, poking holes must be provided, as there is merely an annular space, relatively small in area, which permits access to only certain parts of the furnace. The swinging valves also restrict the free use of the clinkering bar.

A cover is fastened to the top of the hopper by means of studs and wing nuts. The valve and cover should never be open at the same time, nor should the plug in the top of the cover be left out, or a stoppage of the plant will take place.

The vaporiser consists of an annular chamber on the top of the furnace, surrounding the fuel chamber. It is traversed by a flue, through which the hot gases pass on their way from the furnace. The air is drawn in through a pipe in the top of the producer, passes over the surface of the water, and takes up steam on its way. The air and steam then pass down a vertical pipe, through a cock, by means of which the supply may be regulated, into the ashpit, and thence to the furnace (see fig. 28).

The seal box at the bottom of the gas outlet pipe is of a rather novel form. The bottom of the outlet pipe is expanded into a box-shaped receptacle, down the middle of which there is a partition. From one side of this two pipes, one above the other, pass into the waste-water reservoir below. The gas pipe is continued on the other side of the partition and passes into the coke scrubber, the bottom of which is filled with water. These are the conditions that hold while the plant is running. When it is stopped, the cock on the lower pipe is closed, thus causing the water which overflows from the scrubber to rise to the higher pipe. The division plate thus forms a water seal, past which the gas cannot leak back from the scrubber to the generator. The water supply to the scrubber should not be closed until it is quite certain that the seal has been made. The other details are similar to those in the plants previously described.

The Pintsch Plant.—The producer of this plant consists of a wrought-iron cylinder, furnished with the usual firebrick lining, and non-conducting filling. The gas, instead of being made to circulate round the distilling bell, is drawn off through an annular ring which extends right round the producer, and is situated about halfway up the producer. As this exit is entirely formed

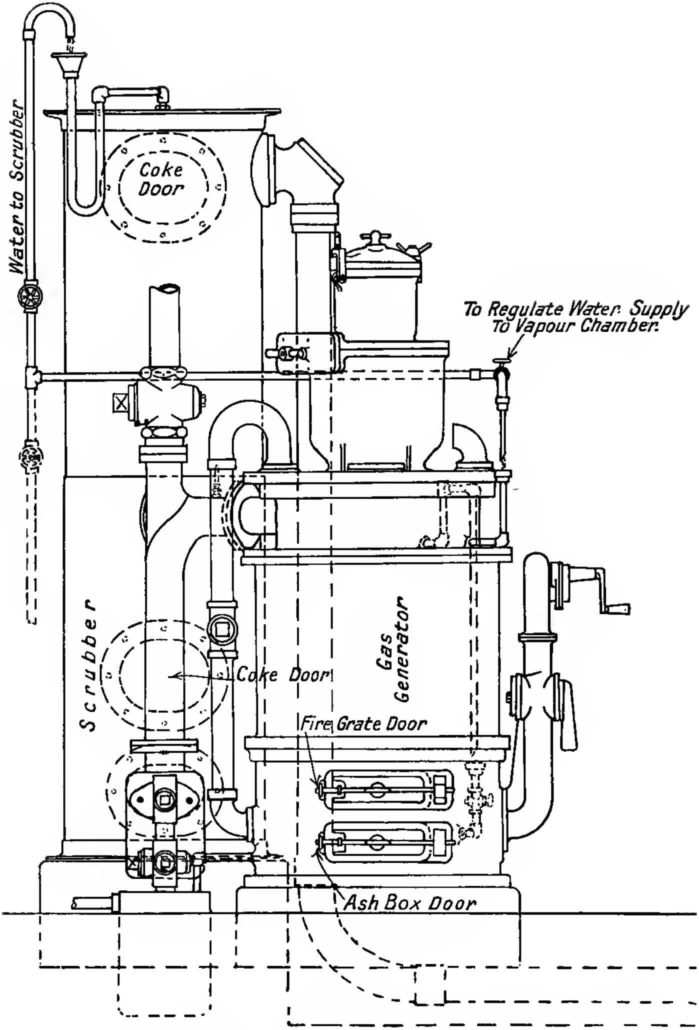

Fig. 29.—General Arrangement of Plant shown in section in fig. 28.

by the firebrick lining, there can be no burning away of metal, while the entire heat of the gas is available for coking the coal as it settles down through the contracted area. There are here no cold surfaces to favour the deposition of soot, while the small portion of firebrick exposed to both fuel and hot gases ensures that the coking operation shall be gradual, and that there shall be no excessive yield of tarry matter, even with a heavy charge of raw fuel. The hopper is of the revolving hood type, and is similar to that used in the Crossley producer. The grate merely consists of firebars, which rest on a projection in the firebrick lining. On p. 7 is illustrated an early form of this producer.

After leaving the producer, the gas passes through the straight vertical tubes of an external vaporiser. These tubes are enclosed in a cylindrical casing, and are surrounded by water. The steam thus formed from the heat of the gases passes into the ashpit, and then upwards to the furnace.

The gases and tar vapours obtained through the heating of the fresh coal are led through a suction injector from the top by means of pipes to the ashpit. Here they are burnt, and the carbon dioxide and water vapour formed mix with the air and steam coming from the vaporiser, and pass upwards into the furnace, where they are reduced to hydrogen and carbon monoxide. In this way the makers claim that they get rid of all tar in the gas, and that non-caking bituminous fuel may safely be used with this type of plant (see Appendix III.).

At the bottom of the vaporiser is a seal box, which has a partition extending vertically a little more than halfway down the box. When the plant is stopped, the surplus water from the scrubber overflows into this box and completes the water seal. This seal box also acts as a separator to precipitate the coarser particles of dust, as in the Campbell plant. The gas then passes up the coke scrubber and down a pipe into the sawdust cleaner. This is similar to that of the Crossley plant, but occupies more room, both on account of its shape and from the fact that it is on a separate foundation to the scrubber. A special feature of the Pintsch plant is the pressure governor, which is placed between the sawdust scrubber and the engine. It is a small gas holder of the ordinary type, of about three to four times the volume of the engine cylinder. When gas is sucked by the engine, the bell of this governor falls, and after the suction stroke the bell is made to rise by a spring on the top. This reduces the pressure in the main, and provides the necessary suction to draw gas through the plant. Its object is to equalise the pressure of the gas in the main leading to the engine. A governor of this kind is useful when two or more engines have to be run from the same producer, as it ensures the generation of gas of a more uniform composition. For separating the water and reducing the irregular suction of the gas engine, Messrs Pintsch advocate the use of a water separator immediately before the gas engine. They state that if the above pressure governor is used, this separator may be made smaller than would otherwise be required, and give the following instructions:—

A water outlet must be situated at the lowest part of the separator. This outlet may be arranged in one of four ways:—

(*a*) A 1-in. pipe may be put into a seal pot so that the water may be constantly drawn off. This arrangement can only be made if the height of the suction is more than 16 ins.

(*b*) A 1-in. plugcock may be fitted, and should be freely accessible.

(*c*) A water separator pump is specially recommended for separators deeply situated in channels.

(*d*) A drain pot with two cocks.

The gas piping leading to the gas engine should always begin as high up to the top of the separator as practicable.

Mersey Plant.—There are several special points about this plant that are worth noticing. The charging arrangement consists of a cast-iron cylindrical valve, part of the cylinder being removed. It is filled through the hole thus formed, and then rotated so that the fuel contained in the valve is emptied into the producer. Thus there need be only the minimum possible amount of air entering the producer with the fuel. The vaporiser is of the external type, and consists of a fibrous material wound round the gas outlet pipe, the whole being surrounded by a wrought-iron casing. Water is fed on to the fibrous material, and the heat of the outgoing gases thus communicated to it. The steam is led by a short pipe from the vaporiser to a space at the back of the inclined grates. In order to start up

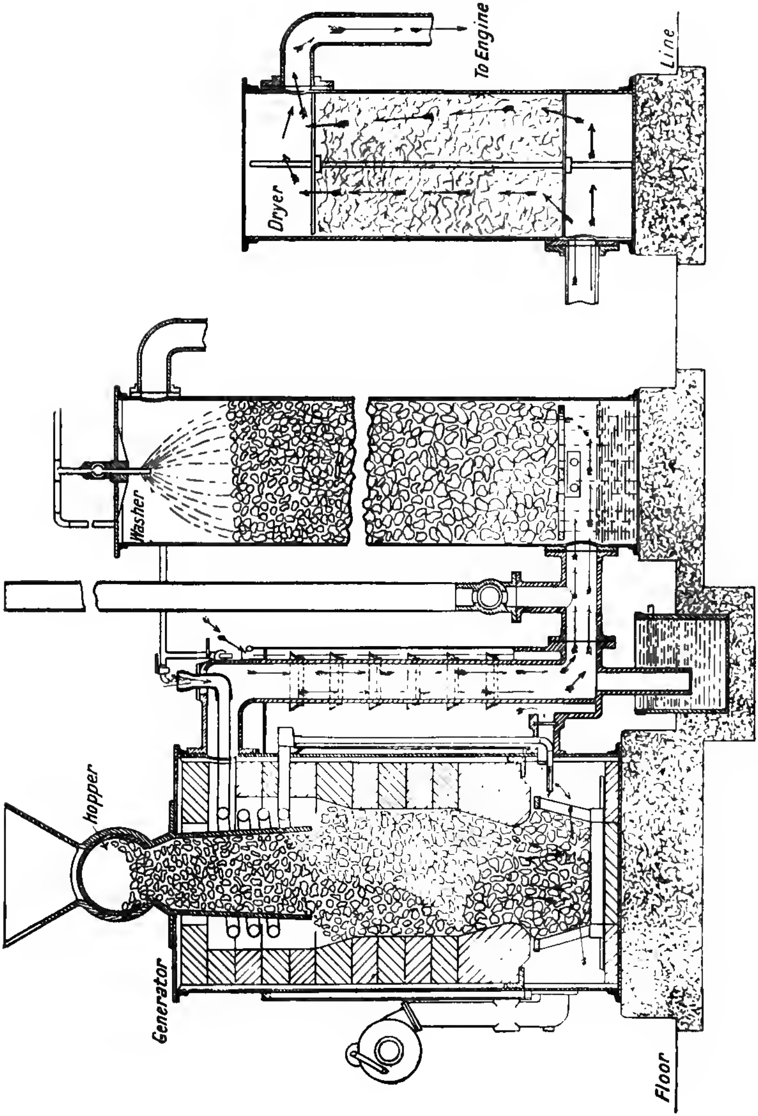

FIG. 30.—See Specification, p. 100.

the plant quickly without waiting for the vaporiser to get hot, an arrangement is made for injecting water into the fuel. As soon as the vaporiser begins to work, this water jet is turned off. This arrangement—so say the makers—enables the ash door to be opened without interfering with the quality of the gas, by starting the jet before the doors are opened. The ash doors themselves are fitted with mica windows, through which the condition of the furnace may be observed. In addition to the ordinary coke scrubber, a dryer is fitted. This consists of a cylindrical casing of mild steel plates, riveted together, and containing two perforated iron plates on a central rod. Between these plates wood fibre is packed, through which the gas passes, being cleaned and dried in the process (see fig. 30).

In the pressure type of suction plants, a power fan is fitted to draw the gas from the producer and deliver it under pressure to the engines. This, of course, has the merit of ensuring an even load on the plant, and combines the advantages and disadvantages of both pressure and suction plants. The following is a specification supplied by the Mersey Engine and Producer Co. for this type of plant, using anthracite coal. It will give the student an idea of how a specification is worded.

Specification.

General.—The plant will consist of a gas generator, air regenerative heater, vaporiser, starting fan and blowpipe, rotary stoking valve, hopper, firebricks, seal box, washer, dryer, chimney valve and piping, power fan, automatic pressure regulator, together with the necessary gas pipes for connecting these parts, and also water pipes for connecting the different points where water is required for the producer, so that it is only necessary to connect the water service at two points. Drain pipes from seal to washer are provided for coupling to the seal box.

Each item has been carefully considered, with the result that the plant has been brought to the greatest commercial efficiency. The plant being practically automatic and simple in operation, the person looking after the gas engine can attend to the plant.

The gas is produced by means of the vacuum created by the power of the fan, the suction side of which is connected up to the washer, the pressure side through pipes to the dryer, and from there wherever it is required to be used.

The automatic regulator is so arranged that it will adjust the supply equal to the demand. Should no gas be required, the automatic regulator completely closes the outlet. When a partial or full supply is necessary, the regulator automatically opens and permits just the right quantity to pass, the fan drawing in the hot air and vapour through the heated mass of fuel, thus generating the gas. The gas passes down through the interior of the vaporiser, keeping it constantly at a temperature sufficient to evaporate the water. After leaving the vaporiser, the gas passes through a washer, power fan, regulator, and dryer. The cleaning portion is so arranged that the gas, in passing through, is freed from all dirt, etc., and delivered dry, so preventing trouble from sticky valves, premature ignition, etc. etc.

Owing to the arrangement for injecting the water into the fuel, the plant may be started up in a few minutes, it being unnecessary to wait until the mass of brickwork, vaporiser, etc. gets hot, the steam resulting from the jet taking the place of the steam which is normally drawn from the vaporiser. After the plant has been running a few minutes, the vaporiser heats up and starts to generate vapour, when the water spray may be turned off. This arrangement also enables the ash doors to be open without interfering with the quality of the gas, by simply starting this jet before the doors are open, and the plant to run for long period without shutting down for clinkering.

Generator.—The generator is of cylindrical type, and built up of riveted steel plates, lined with special firebricks. The generator is stoked at the top through a cast-iron rotary valve, on top of which is the hopper. This charging valve has been designed for the purpose of feeding the generator with fuel, and preventing air being drawn in during this operation. The ash doors are hinged and fitted with mica windows.

Vaporiser.—The vaporiser consists of an iron tube, round which is wound special cups over which the water passes, thus offering a large surface to the heated pipe for evaporation. The vaporiser is enclosed by a wrought-iron cover. The arrangement of the vaporiser is such that although the gas enters it at a high temperature, it leaves it practically cold, thus showing the efficiency of the arrangement.

Starting Fan.—The fan is of the pressure type with the necessary gear, so that the plant may be started quickly and with but little exertion. The larger sizes are fitted with ball bearings.

Washer.—The washer is of circular type, built up of mild steel plates, properly riveted, so as to be thoroughly gas-tight, fitted with a cleaning door. In the bottom of the washer, iron grids for carrying the coke to be fitted, the coke being provided by the purchaser. A suitable seal pipe is fitted at the bottom of the washer for draining away the wash water.

The water enters through a special form of nozzle which can be removed in a few moments, so that, should dirty water be used and the spray choked, it is unnecessary to break joints, etc.

Power Fan.—One power fan of special design to ensure high efficiency, and to enable it to meet the special conditions under which it has to work, encased in a suitable cover and fitted with special type of stuffing box, fast and loose pulley, with ample area in the bearings to ensure cool running.

Pressure Regulator.—This regulator is of special design, and constructed of a combination of steel, gun-metal, and cast iron. It is simple in design, yet extremely sensitive, to enable it to respond instantly to such variations in the load as may occur. The adjustment is such as to make it entirely automatic in its action.

Dryer or Expansion Box.—The dryer is constructed of mild steel plates, riveted together, and containing two perforated iron plates carried on a central rod. Between these plates is packed wood fibre, thus ensuring absolutely dry and clean gas.

Tools.—Two clinkering bars are provided, one straight and one bent, to enable the whole of the inside of the producer to be searched.

Sundries.—Six feet of straight chimney pipe is provided, also cocks for regulating the water supply.

Full erecting and running instructions are provided.

Where erection is included in the quotation, all lifting tackle, foundations, unskilled labour, structural alterations, and all cutting away and making good again, must be provided by the purchaser, unless otherwise arranged. The water supply and drains must also be brought up to the plant by the purchaser. (For gas, water, and exhaust pipes, see conditions of contract.)

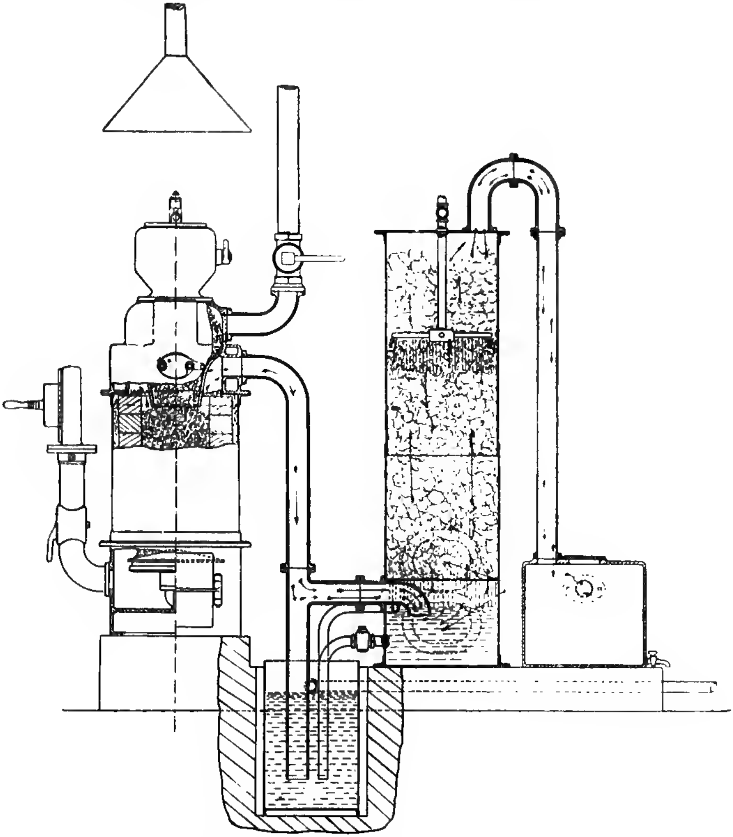

FIG. 31.—Arrangement of Producer Plant in which Rotary Grate is used.

The "Fielding" Plant.—The special features of the "Fielding" producer are the vaporiser, air supply, and grate. A belt E (fig. 32) is formed in the sides of the hopper casting, through which the air supply is drawn. As the hot gases pass round this belt they impart some of their heat to the incoming air, which thus receives a preliminary heating. The air then passes down the vertical pipe C, to the centre of a rotatable table which supports the grate. The latter is simply a circular plate with ribs on its lower side, which support it on the table, and to which it is secured in such a fashion that the two rotate together.

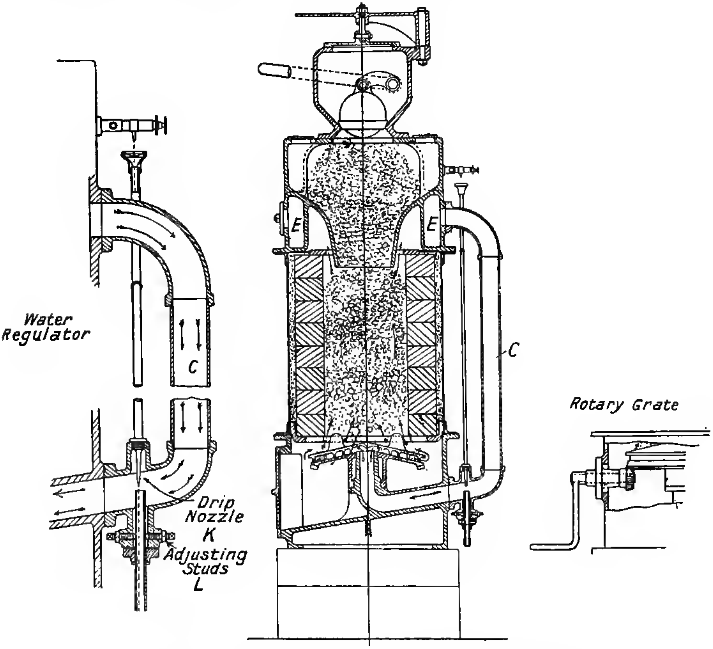

FIG. 32.—A Generator fitted with a Rotary Grate.

The air, introduced at the centre, passes outwards between the ribs to the edge of the grate, from which it passes upwards to the fuel. This method of distributing the blast seems to be on the right lines, as it ensures a regular distribution of air through the whole area of the producer, and does not allow the whole of the blast to take a short cut through one part of the fuel. The steam carried with it is superheated in its passage between the grate and the table.

The water is introduced into the air pipe C by means of a drip nozzle K, from which it falls as a series of drops. A waste pipe is provided immediately below the nozzle, and through this the whole of the water supply passes if the velocity of the air does not exceed a certain value. If the engine is working, at each stroke the rush of air through the pipe C carries along with it some of the water from the drip nozzle, the amount thus supplied to the furnace being proportional to the velocity of the air current, *i.e.* to the load. If a cut-out occurs, there is no rush of air, and so no steam is supplied. The makers claim that this arrangement forms an efficient solution to the difficulty of regulating the water supply for charge of load. As shown at L, the drip pipe can be adjusted by means of studs and lock nuts, so that it can be deflected more or less from the line of drip, and the supply of water to the producer can be regulated at will.

The fireplate is maintained at a fairly uniform temperature by the even distribution of blast, and is provided with studs on its upper surface for the purpose of breaking up the core when the table is rotated. This latter operation is effected from outside the producer by means of bevel gearing, teeth being cast on the lower surface of the supporting table. Fig. 33, p. 109, shows arrangement of this plant and the space occupied.

"Pierson" Plant.—The peculiarity of the Pierson producer is, that it has no grate. The bottom of the producer body is left open, and the fuel rests on a plate placed a few inches below the bottom of the casing. The fuel is held in the furnace by the ashes, which form a cone resting on the iron base, and are easily removed. It is claimed that this arrangement makes the producer easy of access for cleaning purposes, and the ashes can be removed while the producer is at work. Another feature is a vertical poker which is worked by a lever through a hole in the base plate. The fire is thus stirred from below without entirely extinguishing the cone of ashes. The air needed for combustion enters through the free opening between the bottom of the casing and the cone of ashes. One advantage of this type of producer is that, since there is no grate, coal as small as $\frac{1}{2}$ or $\frac{1}{4}$ inch can be employed, and has, it is said, been successfully used even with a percentage of ash as high as 28. The makers state that this plant, owing to its facilities for cleaning, may be run for a week without stoppage, and that the gas will give a mean pressure in the cylinder of the engine of about 85 lbs. per sq. in.

The disposition of the vaporiser is also somewhat singular. It consists of a water-cooled casting at the base of the fuel bed, the steam formed there passing into the free opening between the producer body and the ash cone. It is claimed that vaporisers placed at the base of the fire are more regular in action than those placed above, because the temperature of the fire does not vary greatly. A further advantage is due to the fact that, being water-cooled, the clinker does not adhere to the wall of the producer as it would with an ordinary firebrick lining, so that the lining itself needs less repair, and the labour of removing clinker is avoided. The charging hopper is of a different type to any that we have hitherto mentioned. It consists of a large cast-iron cock, having an interior operating handle and an opening. The hopper itself has a lid through which coal can be charged when the cock is closed. The lid is then shut, and the cock opened to allow the fuel to fall into the furnace.

"Thwaite" Plant.—As an example of the inversed draught type of plant, we cite the "Thwaite" producer. The fuel is fed into this producer by a hopper at the top in the usual way. This hopper has an opening, the area of which is controlled by a valve at the side to admit the "primary air." The fuel ignites, and the gases formed are drawn *downwards* by the engine draught through a grill below the conical fire-grate. The gas then passes to the scrubber through a pipe connected to the space below the grate. The ash and clinker gravitate into a hydraulic bath in which the producer is supported, and are removed by means of rakes. There is, however, a secondary air supply which is admitted about half way down the producer, through ports distributed round the shell. This secondary supply, causes the temperature in that region of the producer to be very high, so that the tarry vapours generated in the upper zone become fixed, and the dirt carried by the gas is burnt up. This scrubbing action is only useful, of course, when a comparatively small amount of volatile hydrocarbons is present in the coal. The secondary air supply may be regulated at will by means of a belt extending round the producer, which opens or closes the ports as desired. This plant is also provided with an ingenious governor arrangement, which maintains a continuous suction on the generator, and enables the engine to draw its supply without excessive wire drawing.

"Dowson" Plant.—The special feature of the Dowson plant lies in the method adopted for charging the air with moisture. The upper part of the producer is surrounded by a jacket filled with broken coke or some similar material, and through the porous belt thus formed the air supply is drawn. A sprinkler arranged above the belt keeps it moist, while the heat passing from the gas-filled space at the top of the generator keeps it warm, and so the air on its way to the fire becomes heated and charged with water vapour. The supply of water is regulated by a feeding device, which consists of a closed vessel fitted with a water inlet, an overflow pipe, and a connection to the spraying ring of the vaporiser. At each suction stroke, the pressure being reduced in the vaporiser and its connections, the water rises in the belt above the level of the outlet, and thence falls down the spraying ring. This serves to regulate the supply of water in proportion to the load. The ashpit is of the dry-bottom type, allowing the fire at its base to be kept at a higher temperature than with the wet-bottomed ashpit. It also allows the incoming air and steam to be superheated to a greater degree. The higher temperature, however, though conducive to economy, encourages the formation of clinker. A section of this plant is shown fig. 9, p. 18.

The "Watt" Plant.—The vaporiser of the Watt producer is again different to those we have hitherto seen. The gas leaves the producer through ports which extend all round the top of the producer. They then pass downwards between the shell of the producer and an external jacket, which is arranged so as to leave an annular space between it and the producer shell. The outside of this shell has a spiral trough cast on it, and round this again a second shell is arranged so as to entirely envelop the producer. The body of the producer is made of a number of steps, conical form, and is also enveloped by this external shell. Water is introduced at the top of this conical cover, and flows down into the spiral trough already mentioned. These two form

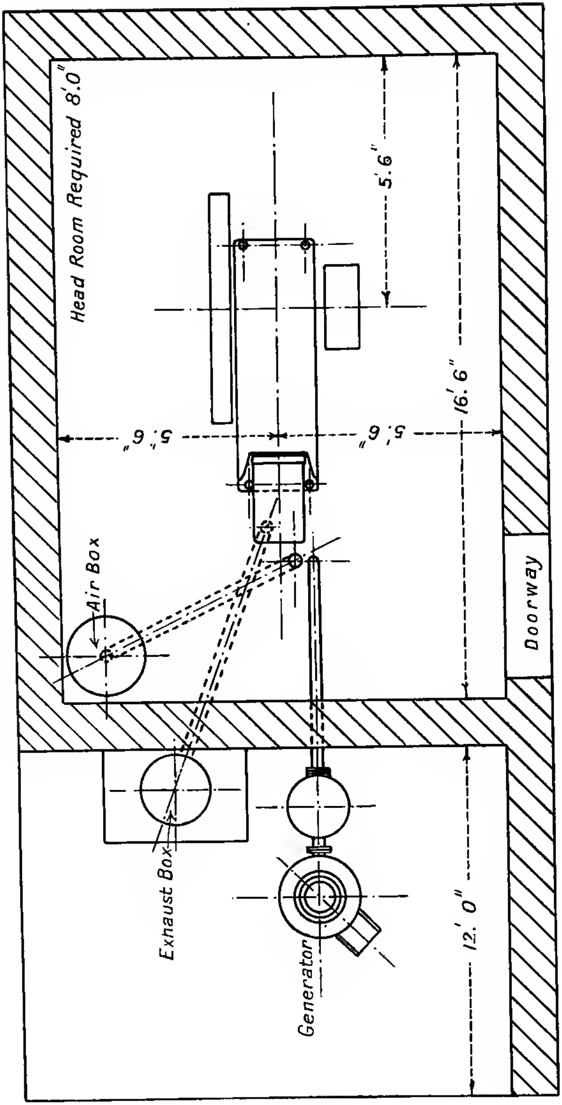

FIG. 33.—Arrangement of 55 B.H.P. Gas Engine and Gas Plant.

the vaporiser, which thus completely envelops the producer. The air is also introduced at the top of the cover, and passes downwards through the external jacket, taking up heat from the interior jacket through which the hot gases are passing, and picks up steam on its way to the furnace, the action being thus regenerative.

It is noticeable that no fan is used to start up this producer, the necessary draught being supplied by a chimney, arranged to act when required by means of a three-way cock, and which allows the producer to be connected to the scrubber or the chimney as desired.

A special feature of the scrubber is a flexible diaphragm top cover, which acts like the gas bag of a pressure plant, allowing a full supply of gas to pass into the engine, and steadying the pull on the producer.

"Whitfield" Plant.[1]—The vaporiser of this plant is again the special feature. The water is pre-heated by passing through a tube which is coiled round the distilling bell inside the producer. The vaporiser proper forms part of the vertical pipe that conveys the gas from producer to scrubber. This is made of cast iron, and a coarse screw thread is turned on its outside surface, the upper faces of the threads having a downward inclination towards the pipe. The water from the pre-heater is fed on to this thread drop by drop, and descends above the whole surface of the thread, being vaporised by the heat of the pipe. This part of the pipe is surrounded by a casing, open at either end to the air, and connected at the middle to the ashpit of the generator. Air is drawn in at both ends by the suction of the producer, takes up steam on its way through the vaporiser, enters the ashpit, and, passing upwards, supplies air and steam to the fuel. The proportion of water run over the screw is suited to the general conditions of the work.

Another point worth noticing is that the starting fan is placed between the generator and the engine, so that the producer is *always* under atmospheric pressure, no leakage of gas into the air being possible. Other details of this plant are similar to corresponding parts in some of the preceding ones.

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[1] See Bibliography.

LECTURE III.

PLANTS FOR SPECIAL PURPOSES.

Suction Gas Generators for Fuel containing Tar, and especially for Bituminous Coal.—If an ordinary suction gas generator, constructed to gasify anthracite or coke, were charged with bituminous coal, the contents would be distilled off as lighting gas and tar vapour when the coal reached the hot zone. During the conversion of the remaining coke into generator gas of normal composition by the steam and air mixture which enters the generator underneath the grate, the produced lighting gas and tar vapour would mix with this gas.

No disturbing effect would be caused by the lighting gas, but the tar vapours, which are cooled down in the washing and purifying apparatus, would condense into a more or less tough, sticky liquid, and in this condition easily clog, after a short time, the apparatus and piping, in addition to the seatings of the gas engine valves.

By erection of purifiers of very large dimensions, and arranging them in a similar manner to those used in town gasworks, it is technically possible to entirely free the gas from this tar, but this course would not be economical. The apparatus necessary would be very complicated and expensive to erect, and would not only require a large space, but also careful attention. In addition, the waste water of such a power gas plant, mixed with various organic particles, is more or less impure, and has such a bad smell that in many cases it would not be allowed to drain off into the municipal sewers, rivers, or any other public waters.

The present question is, whether it is possible to construct the producer plant or conduct its working in such a way that the tar vapour can be destroyed in the generator immediately after being freed, in which case the purifying apparatus has not to free the gas from tar, but only from flying dust. If this can be done successfully, the required parts of the apparatus are reduced again to the plant necessary in suction gas plants using anthracite or coke.

The trials undertaken in this direction by Messrs Julius Pintsch of Berlin (1903) have, it is claimed, been accompanied by great success. After the particular system of gas producer had been thoroughly tested in continuous working at their works at Fürstenwalde, using the fuel in question, suction gas installations of this kind were also supplied to other works.

The generator consists essentially of two zones: a lower gasifying zone and an upper zone in which the freshly charged fuel is distilled, and which passes the resulting coke to the lower zone, where it is converted into producer gas.

One part of this gas ascends through the specially built channels and collects in a ring channel, and then passes through the vaporiser and the cleaning apparatus to the gas engine. The other part is sucked into the upper zone by the steam-jet exhauster in order to extract, by its high temperature, the lighting gas and tar vapours from the coal, so completely that only coke, pure and free from tar, reaches the outlet of the lower zone. The products of distillation pass, together with the hot gases coming from the lower zone, to the exhausters, from whence they are blown into the fireplace in order to be entirely and freely burnt in the flame with the air contained in these spaces, and pass into steam and carbonic acid; thus they are changed into permanent gases. The combustion products generated in this way and the steam for working the steam-jet exhausters, mixed with superfluous air, penetrate the incandescent coke under the lower zone, where the carbonic acid and the steam are reduced to carbonic oxide and hydrogen, viz. inflammable gases.

There is no loss of heat by the combustion of the distillation products, as the heat produced is introduced with the air entering the incandescent fuel together with the combustion products.

The steam required for the working of the steam-jet exhausters is produced in the vaporiser at a pressure of from 3 to 5 ft. water column, the vaporiser being heated by the hot gas passing to the engine.

When starting the generator the coke has to be brought to a light red incandescence. This is done by means of the fan which blows air into the generator, and the combustion gases are allowed to pass straight into the open through a pipe. In this way the water in the vaporiser is brought to a boiling point, so that when starting the engine the steam-jet exhausters can be started as well.

The generator is shut off from below by the cast-iron pipe being immersed in water, so that the greater part of the ashes and clinkers can be cooled easily and removed from the generator without an interruption of the working or any other disturbances while generating gas.

There are no grates or other iron parts coming in contact with the fire in this generator, which is a distinct advantage, as they are always more or less exposed to wear or tear. By this the durability is considerably greater, in comparison with ordinary generators having grates.

As seen from the above, the tar contained in the coal is made entirely harmless by *burning* it outside the fuel in superfluous air. Hereby the system differs considerably from other constructions, which, by conducting the tar gases through the incandescent fuel, only effect the *decomposition* of the distillation products. The advantage of this generating system, arranged with tar combustion, supplies gas to the engine entirely free from tar and soot; when bituminous coal is used this cannot be too highly commended, especially for continuous day and night work, and where a sensitive valve mechanism (for instance, self-acting valves or slide valves) are used.

A further advantage of the destruction of the carbo-hydrogen compounds contained in the coal is the almost entire absence of odour of the scrubber water, which, even in coke or anthracite generators, is slightly noticeable. Complaints of bad odour of waste water, which are sometimes made with other generators, will not arise with this system of tar combustion generator.

The efficiency of the generator when using bituminous coal is about 70 per cent., the quality of the gas being about 105 B.T.U. The calorific value of the gas is therefore lower than in generators for anthracite or coke; the gas is of about equal quality to good blast furnace gas, and, like this, has the advantageous quality of being especially suitable for the working of large gas engines. The content of hydrogen does not exceed 14 per cent.

The importance of the construction of this generator is its economical use, and being much more independent of the kind of fuel to be used. If only fuel free from bitumen could be used, these generators with tar combustion would permit of gasifying anthracite, gas, or foundry coke, as well as anthracite coal, bastard anthracite, and especially bituminous coal.

Should a bituminous coal cake very much, it will be necessary to mix it with non-caking bituminous coal, anthracite, or coke.

If provision is made that the exhausters are not fed with steam, but with compressed air of a pressure of 4 ft. to 6-ft. water column, produced in a blast apparatus driven by electricity or the engine itself, this system is also suitable for using dry peat or brown coal briquets.

Moist peat and moist brown coal or wood may also be gasified if mixed with bituminous coal, anthracite, or coke. In cases where fuel containing a quantity of water is used, the vaporiser is left out and an air superheater substituted (this being cheaper), and connected to the generator; the heat of the gas is transferred to the air on its way to the generator, and is thus partly recovered.

It is also possible to arrange the vaporiser and air superheater side by side without difficulty, in order to make the plant suitable for the use of bituminous coal, anthracite, or coke, as well as for moist fuel, brown coal briquets, peat and wood.

With regard to the wood generators of the Compagnie du Gaz Riche of Paris, these have two generator shafts, which have to be separately charged, whereas the aforesaid system has the advantage of having only *one* shaft, thereby saving the loss of heat.

For a fuller description of the methods employed for the destruction of tar in power gas, see Appendix III.

Plant working on Air Supply alone.—It is usually accepted that if air alone is used for working the producers a high temperature of combustion is obtained, and the formation of clinker is increased. This naturally leads to increased difficulties of working and a heavier amount of wear on the producer. There is also obtained a gas of less calorific value than when steam and air are both used. It would certainly simplify matters if the steam supply could be dispensed with, and in this connection the remarks of Mr Godfrey M. S. Tait,[1] who gives results of some interesting experiments, will be quoted.

He says that certain defects noticeable in the older type of pressure producers are all more noticeable with suction gas producers than with the older types. These defects are (1) variation in the quality of the gas; (2) the difficulty of cleaning the fire without interfering with the manufacture of the gas; (3) the necessity of a spare unit.

Troubles have been known in many suction gas plants used in conjunction with gas engines. The gas changes in a manner beyond the control of the man in charge of the plant.

Now, Mr Tait advances the proposition that "the thermal or calorific value of the gas employed does not necessarily form a true index of the power value of a gas for engine work."

The experiments which led him to make that statement are of great interest. He took a gas engine rated at 100 H.P. on producer gas containing hydrogen (obtained from the steam supply), and having a total calorific value of 138 B.T.U. per cubic foot. Under the most favourable conditions in the producer, no clinkers, and a sufficiently high temperature, he obtained 106 H.P. (he does not say whether *brake* horse-power or *indicated* horse-power). He then removed the steam supply apparatus. His gas from the producer was now free from hydrogen and had a calorific value of 91 B.T.U. per cubic foot. But with this gas of lower calorific value he was able to develop 114 H.P. Finally, however, the producer became overheated.

His next move was to use the exhaust from the engine under the furnace of the producer, in order to dilute the incoming air. This reduced the temperature of the furnace. A patent process for flame and combustion temperature regulation was used for this purpose.

It is now well known that it is economical to increase the compression of an internal combustion engine as far as is possible without causing premature ignition. Incidentally, it may be mentioned that such premature ignition is usually due to the hydrogen in the gas. Mr Tait, knowing that when he supplied air only there was no hydrogen, increased the compression up to 200 lbs. per sq. in.

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[1] *Cassier's Magazine*, Gas Power number.

This arrangement was quite satisfactory. The engine worked much better. Troubles of back-firing and pre-ignition, which had been experienced before, now disappeared. The engine developed 126 H.P., and would carry 110 H.P. with great ease for a continuous period. The total efficiency of the engine increased considerably.

He attributes the increase in horse-power and efficiency chiefly to the *absence* of hydrogen. Mixtures of gases, the components of which burn at different rates and velocities, may not be well suited for engine practice. The ignition is conceivably too early for the hydrogen—a gas of a very combustible nature—or too late for the slower burning carbon monoxide.

This is certainly a matter which will receive much fuller investigation. It would appear, from the limited data procurable, that gas which contains only one combustible element gives a much more steady and regular run to the gas engine.

On the other hand, it is by no means certain that a satisfactory apparatus for regulating the temperature of the furnace without the use of steam has been devised.

Mr Tait has installed a suction gas producer for the John Thompson Press Company, on the principle of no steam supply. It consists of one suction producer and two vertical three cylinder engines of 125 H.P. and 50 H.P. respectively. The plant is at work under exacting conditions. It operates twenty-four hours per day on from maximum to low load, and is stated to give no variation in the quality of the gas, or trouble with clinker. Apparently, compressions of 200 lbs. per sq. in. cause no trouble with back-firing.

Having described the various distinctive features of the various plants and their working, we now wish to get some idea of the number of suction plants at present working, and the size to which this type of plant may be enlarged for supplying an engine or engines of large power.

TOTAL H.P. OF SUCTION GAS PLANTS.

It is, of course, very difficult to obtain a concrete idea of the total B.H.P. of suction gas plants which have as yet been manufactured. An enormous export trade has been done by the makers in this country during the last few years. The Power Gas Corporation Ltd. write to inform me that the approximate H.P. supplied in suction gas producers within the last twelve months has been about 7000 H.P. They estimate the depreciation at 2½ per cent. of the first cost of the plant. In reply to an inquiry, Messrs Crossley say:—"We have built suction plant gas producers of 500 H.P. capacity, and are in a position to build them of 2000 H.P. size units if necessary. This, of course, refers to purely suction producers, but, as far as other power plants are concerned, we have already constructed producers under pressure system of 2000 H.P. size per unit. We are at the present time building a plant to give 7000 H.P. capacity, and we have recently erected one at Winnipeg of 4500 H.P. capacity, also of the pressure type, supplying six large engines coupled direct to high-pressure water pumps. We have also supplied several large central stations abroad with this type of plant, and, from the experience gained with these large units, we should have no hesitation in building a suction plant of 2000 H.P. capacity. You are quite right in assuming that our plants are made to practically work continuously without duplicates, and we have a great many installations running in this manner." In addition to being pioneers in this work as far as England is concerned, this firm have now supplied nearly 300,000 H.P. of plants to work on all varieties of fuel, including bituminous coal, lignite, charcoal, peat; and, indeed, advertise the fact that they are prepared to make plants to work on any carboniferous fuel.

Messrs Campbell began in 1904 to manufacture suction gas plants, and have now already turned out about 130 plants up to 250 H.P. Orders are increasing so rapidly that they have extended their premises considerably, and now employ 1000 men constantly.

Mr Rowan states that Messrs Crossley have supplied or have on order a plant aggregating 100,000 H.P.

So far as I have been able to ascertain, Messrs Pintsch have made the largest suction gas plants. They have a 2000 H.P. suction gas plant, serving six engines of 350 H.P. At the Municipal Electricity Works at Scheveningen, Holland, there are six generators which deliver gas to a common main, and from this main there run three pipes which pass into scrubbers. These scrubbers seem to be very high, but are otherwise of ordinary type. From the scrubbers the gas passes on to the purifiers (there are six of them), and then it goes to one common main, from which each gas engine draws its supply. The expansion boxes are provided near the inlet valves of the engines. It has been found from working experience that the consumption of anthracite is ·75 lb. per H.P. hour. It may be mentioned that this Pintsch generator is so designed that it will use bituminous coal, peat, and wood shavings, as well as anthracite or coke.

In fact, there seems to be no difficulty in manufacturing suction plants of any size that may be required, though, as I have already pointed out, pressure plants are usually preferred for large sizes, as the extra capital outlay on scrubbers and cleaners is not such a serious matter as in the case of small powers. Moreover, in plants of 1000 H.P. or more, the ammoniacal compounds given off from the coal are often separated and recovered as ammonium sulphate by means of sulphuric acid. In this way the revenue resulting from the sale of the sulphate (which is used as a fertiliser) serves to considerably diminish the running costs, and in some cases completely covers the cost of the coal used in the producer, so that those makers who now say that they can produce 10–20 B.H.P. for a penny, would then probably state that they could do so for nothing at all. For these reasons, therefore, it is not likely that the suction gas plant will ever be much used beyond about 500 H.P., but that it will find its proper sphere in the generation of power for small units. An exception may, perhaps, be made in the case of marine work, where the practical impossibility of leakage of gas into the air is an important advantage, as the producers will probably be in enclosed spaces. The reliability and simplicity of the suction plant will then be more in its favour; and as questions of space and weight at sea are very important, it is likely to be preferred to the pressure type of plant, even in large sizes.

ADVANTAGES AND DISADVANTAGES OF THE SUCTION GAS PLANT.

Arguments against their Use.—It is a noticeable fact that when, in the past, papers on suction gas plants have been read before engineering societies, the discussions which have followed have usually shown that engineers do not take kindly to new inventions. There are usually to be found people who will predict failure. But what is wanted for progress is encouragement. It is so easy to pull down, so difficult to build up. It takes a great heat to arouse enthusiasm, and but a little water to damp it. And yet we all want progress in our engineering work, and it is only by great enthusiasm that progress is possible.

Most of the prophecies for failure of suction gas plants would apply equally well to other types of power producers. The opponents of these plants do not usually attack them on the score of economy. They are proved to be economical by facts which cannot be contradicted. But there are often heard warnings of failures, of town gas connections, of the cost of duplicate plants, and of the dangers of poisoning by the gas. One might easily argue that steam boilers and pipes had been known to burst and kill people, and that the heat from the boilers had been known to cause fires. Such a method of argument is not to be commended, and it is, after all, better to have facts than opinions. And to return to the subject of fuel economy, it has often been stated that, after all, that does not count for much. But surely it is the duty of the engineer to save every penny that can be saved in power production. Another argument, which is certainly of some consequence when marine work is discussed, is that the gas engines are not reversible. That is quite true. Many engineers have been working at the problem, but it has not been solved up to the present. Doubtless, with improvements of double acting gas engines, reversibility would come in the future. It would appear to be necessary to have an ample supply of compressed air upon which to draw.

Criticism has also been frequently levelled at the results of the trials conducted by Captain Sankey and Professor Dalby for the Royal Agricultural Society at Derby. It has been said that the plants, although they gave good results, were especially constructed for the trials. But the trials were arranged for working conditions. It seems to be a pity that the Society of Arts cannot make arrangements for a longer series of trials. Incidentally, it may be mentioned that one very important result of the Derby trials is often overlooked. And it is, that there is apparently very little to choose as regards economy of working among all the various suction gas plants on the market.

Advantages of the Gas Plant.—We will now pass on to consider some of the advantages of the gas plant in general, and the suction gas plant in particular.

One advantage which a gas engine has over a steam engine, and which is not always realised, although it is self-evident, is that it can be installed comparatively easily. This is especially the case where street gas is laid on to the buildings in which the engine is to be placed, but it is not very difficult to make arrangements for putting in place suction producers, and the recent improvements in the various types of these useful generators lead one to suppose that they will be more generally adopted. The advantage of having to provide no chimney and condensing apparatus, as in the steam engine, is very considerable, and it has been estimated by experts that when a gas engine uses street gas, the trouble of installing the same is less than one-fifth that of the steam engine and boiler. The foundations of a gas engine cost about one-sixth the money required for those of a steam engine, and there is a great saving in high-pressure steam piping. The Continental authority, Mr R. E. Mathot, tells us that, comparing a fifty horse-power steam engine, having a pressure of ninety pounds and a speed of sixty revolutions per minute, with 50 H.P. producer gas engine (in the case of the steam engine reckoning the cost of a boiler of suitable size, foundations, brickwork, smoke-stack, etc.), it is found that the installation of the steam engine entails an expenditure some 15 per cent. greater than is the case with the producer gas engine. And in addition to this the cost of operating and maintaining a steam engine of 50 H.P. will be some 40 per cent. greater than the operation and maintenance of a producer gas engine. Hence it is clear that in sizes from 10 to, say, 500 H.P., the suction producer gas-driven engine has a great advantage over the steam engine in cost and maintenance. And there are many who endorse the views of Mr H. A. Humphrey, that in powers greater than these it is more economical and advantageous to use Mond producers and gas engines, for the ammonia can be recovered in producers of that size, and the gas can be generated, distributed, and sold at a profit at the ridiculously low figure of of twopence per thousand cubic feet, which, bearing in mind the relative calorific value of Mond gas and illuminating gas, is equivalent to the latter at eightpence per thousand cubic feet. But the problem of the transmission of gas is a very big one, although it is commercially possible.[1] Indeed, projects have been made to gasify the coal at the collieries, and transmit the power by means of gas mains. The principal drawback to this is the capital cost of the main, which is exceedingly high. Indeed, if such a transmission is worked out from both the efficiency and financial points of view, it has been estimated that, with ordinary load factors, about thirty miles is the upper limit for the transmission, except, perhaps, in the case of new countries, where the line cost may be diminished.

It may be well to point out here that one great advantage of the suction gas plant, as compared with the pressure plant, is that it does away with the gas holder and elaborate washing apparatus. This consequently saves both money and space. There is no separate boiler for steam raising ; thus the plant is self-contained. The production of gas is automatically regulated by the demand from the engine. Obviously, it is not necessary to manufacture and to clean more gas than is used. In a word, there is no such wasteful process as blowing off steam in a boiler when the pressure gets too high. Another great point of the suction producer is that the proportions of steam and air admitted are under control. Therefore, no great trouble is experienced in connection with clinkering, and very little poking of the fire is necessary.

On the other hand, it is not possible to recover a bye-product with suction plants, as has been done so successfully in some pressure producer plants. With the latter the cost of production has been so small on account of the value of the bye-product (ammonium sulphate) recovered that gas is made, piped, and sold to the consumer, as we have seen above, at twopence per 1000 cubit ft. All producer gas is valueless for lighting purposes. Pressure plants can utilise slack coal that would otherwise probably be wasted. Suction plants—at present in this country at any rate —can only be worked with highest quality coal or coke as fuel.

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[1] See "Power Transmission," by C. A. Smith, *Cassier's Mag.*, July 1908.

It is remarkable what close attention is given to the coal consumption of a producer or plant while it is serving an engine, and yet, while the producer is standing with a fire in it, in many cases no account is taken of the consumption of fuel. Yet, in the matter of stand-by losses, the gas plant has an important advantage over a steam plant. Mr Dowson has investigated this point at great length in his book on *Gas Producers*, and has arrived at the conclusion that, for a number of steam plants varying between 100 and 500 H.P., the average consumption per standing hour is 71·5 lbs., while that for a number of gas plants ranging between 100 and 375 H.P. it is only 3·5 lbs. per hour. Allowing for the higher powers of the steam plant, the difference is still sufficiently great to show a remarkable economy in favour of the gas plant (the difference between suction and pressure plants in this respect would be practically nil). Besides this, during the night, the brick setting of the boiler cools down, and heat is wasted next morning in heating it up again. In a gas plant no such source of waste exists.

The advantage of the "suction" type gas producer as compared with the older form may be briefly summed up as the following :—

(1) No steam boiler or gas holder is required, so there is no liability of explosion.
(2) It does not need constant supervision, but requires to be attended to for a few minutes only every three or four hours.
(3) It occupies only a small amount of floor space, and requires no foundation.
(4) There is no risk of gas escaping (except, as we have seen,

when starting up), as it is generated by suction and below atmospheric pressure.

(5) The apparatus may be fixed indoors, as there is no more danger from fire than with an ordinary stove.

(6) It can be re-started, after being shut down for an hour or so, in a few minutes, and even from a cold condition in from 15 to 20 minutes.

(7) Gas is only generated when it is required by the engine.

(8) No gas is blown or burnt to waste on light loads. But the excellent economic result is undoubtedly the remarkable feature of the "suction" gas producer in connection with the gas engine as a source of motive power.

THE EFFLUENT FROM A GAS PLANT.

It has been suggested from time to time that the effluent from a gas plant is exceedingly harmful to human life. Any waste water which comes from a suction gas plant contains albuminoid ammonia and sulphuretted hydrogen, together with a small amount of solid matter in suspension. Mr W. Mackay gives the following as the analysis of the effluent from a scrubber of a "Campbell" suction gas plant:—

Total solids at 212° Fahr. . . .	25·00	grains per gallon.
Solids in suspension	16·80	” ”
Chlorides, stated in terms of common salt	0·57	” ”
"Free" ammonia	5·74	” ”
Albuminoid ammonia	0·126	” ”
Organic nitrogen	0·53	” ”
Nitrous and nitric nitrogen . .	0·29	” ”
Sulphuretted hydrogen (present as ammonium sulphide)	3·07	” ”
Oxygen absorbed in moist combustion in fifteen minutes	2·04	” ”
Oxygen absorbed in moist combustion in four hours	2·54	” ”
Cyanides, sulphocyanides, ferro- and ferri-cyanides, phenoloid bodies .	absent	

On standing in the air the effluent became milky.

The same gentleman makes the following remarks as to the harmfulness or otherwise of such an effluent, and the treatment necessary for it:—

"In the first place, the solids in suspension ought to be removed by suitable filtration under any circumstances. There is nothing actually harmful in them, but either in a stream or sewer they would deposit, and the effluent would be objected to for that reason, and, I consider, reasonably so. In what follows, I presume the solids in suspension to be removed.

"As for cattle drinking from a stream which the effluent enters, I do not find anything positively poisonous; but if the effluent were in any serious quantity in proportion to the volume of water in the stream, the cattle would probably refuse to drink. But in any case owners of cattle are always liable to blame whatever goes wrong on an effluent entering the stream from which the cattle drink if it contain anything offensive either in smell or appearance. This effluent smells of sulphuretted hydrogen, and the ammonium sulphide on decomposing deposits sulphur, which will give a bad appearance to the effluent on standing—say, in a pool or still part of the stream. The same remark applies to the effluent if discharged over a field. It would make offensive pools.

"Further, with reference to discharge into streams. We see that the proportion of 'free' ammonia is high. Now, though the origin of free ammonia in this case is innocent, yet, in the analysis of waters, free ammonia is one of the factors relied on as evidence, if present in quantity, of contamination by sewage matter. Therefore, as long as the free ammonia is high, there is always a liability of trouble with the authorities having to do with the stream.

"The standards of purity vary in different localities. Thus, with streams that fish live in, they are naturally higher than in manufacturing districts, where the streams are more or less foul.

"Where authorities have a high standard the effluent might be objected to, even if the smell and deposit of sulphur and the free ammonia difficulty were got rid of, on account of the organic nitrogen being rather high. On the other hand, leaving out of account the smell of sulphuretted hydrogen and the deposition of sulphur, the effluent is better than many effluents that I am acquainted with which are not objected to.

"As to sewers, authorities are always suspicious of gasworks, spent liquor, or liquor of that nature, as such often contain tarry matter, which makes the treatment at sewage works difficult. This effluent does not contain any tarry matter, and I do not consider that it should be objected to in a sewer. For my part, as long as tarry matter is kept out, I should have no hesitation in turning such an effluent into the sewer."

The following is an extract from *Gas and Oil Power*, dated April 15th, 1906:—

"'Chemist' writes to us:—'There seems to be an impression abroad, an impression which is being sedulously fostered by the electric-power people, that the effluent from a gas plant is harmful in the extreme, and pernicious to animal life. The waste water from a suction gas plant contains free and albuminoid ammonia and sulphuretted hydrogen, besides a small portion of solid matters in suspension. It is a strong disinfectant, and has no more effect on animal life than would, say, Condy's Fluid. If the waste water was turned into a stream it would do no harm; and unless it was present in a very large proportion, stock would not refuse to drink the water. The effluent from a bituminous plant is equally harmless provided that suitable arrangements are made for removing the tar before the water is discharged. In ordinary practice, the water is used over and over again, and only the surplus which is made by steam condensing in the plant is run to waste. If this water were turned into a river, stream, or canal, it would do no more harm than the water from the jet condenser of a steam engine. Albuminoid ammonia is generally regarded as the evidence of sewage contamination, but not because it is itself harmful. In future, the sanitary inspector will have to keep his eye open for gas plants before he condemns water as being sewage-contaminated."

With such evidence before us, we are, I think, justified in assuming that, provided the solid matter in suspension in the effluent from a suction gas plant be removed, such an effluent, whether turned into a sewer or a stream, will not be harmful either to human or animal life.

COST OF GAS PRODUCTION.

Dead Costs and Running Costs.—We often see, in the advertisements of suction gas plant makers, the statement that they can produce 10 to 20 B.H.P. for a penny. They can do nothing of the kind, and these wild statements only cause suction plants to be looked upon with disfavour when the purchasers find out that they cannot be fulfilled. Under the heading of "fuel consumption" in Lecture I. we have seen that the fuel cost for a suction plant is about ·1 penny per B.H.P. hour. But this is by no means the only cost incurred in running such a plant. There is the slow and silent but inevitable depreciation of the plant, which will entail its renewal in a certain number of years, and which, of course, must be charged against the plant. There is also the cost of repairs over and above the depreciation mentioned; the cost of water for the producer, scrubber, and engine; that of the lubricating oil for the engine, and the wages of the man in attendance on the plant. Besides these costs, which are only incurred in running the plant, and are therefore called "running costs," we have also the interest on the capital expended. This latter is a very considerable item, and must be reckoned with in making the initial outlay on the plant. So that all these items incurred as "dead costs" or "running costs" must be charged against the plant, and it is only when this has been done that the manufacturer or maker is able to state the actual cost per B.H.P. of output.

Capital Cost.—The first point to be ascertained on laying down a gas plant is, of course, the initial outlay necessary for a plant of the required power. The following table showing the costs and particulars of plants ranging between 4 and 200 B.H.P. is compiled from data kindly supplied by Messrs Campbell, and may be taken as fairly representative of the cost of such plants. The figures must, of course, be only taken as a guide, and are published in the hope that they will furnish the reader with some information that may be of service to him.

TABLE SHOWING PRICE OF GAS ENGINES AND SUCTION GAS PLANTS.[1]

(Horizontal Engines, Ordinary Type.)

Brake H.P. of Engine developed with Suction Gas.	Brake H.P. Capacity of Suction Gas Plant.	Price of Engines only with Magneto-Electric Ignition.	Price of Suction Gas Plant complete as List.	Extra Price for Water Vessel for Engine only.	Approximate Nett Weight of Engine only.	Approximate Nett Weight of Suction Gas Plant only.
		£	£	£ s.	Cwts.	Cwts.
4	4	63	75	2 10	21	25
6	6	70	75	3	29	25
8	8	80	80	3	33	34
10	10	90	80	3	37	34
12	12	100	80	5	47	34
14	14	110	90	5	54	42
18	18	125	105	7	69	45
20	20	145	105	7	76	45
25	25	165	105	9	94	45
30	30	185	120	12	110	58
35	35	210	120	12	130	58
40	40	250	130	16	160	73
50	50	300	160	20	210	90
55	55	350	160	20	225	90
60	60	380	160	20	240	90
70	70	410	190	30	285	120
80	80	445	190	30	320	120
90	90	480	225	40	365	160
100	100	550	225	40	400	160
110	110	620	250	50	440	177
130	130	700	265	60	490	190
150	150	850	300	60	545	225
175	175	975	385	82	590	265
200	200	1110	420	90	635	300

Depreciation.—It is difficult, owing to the short time that they have been used, to obtain any figures which will guide us in forming an estimate as to what rate of depreciation should be allowed in suction gas producers. There is, however, no danger from high pressure. There is no reason why the metal work should be scrapped until there are holes in it—unlike a steam boiler in this respect. There is wear and tear of the brick lining, but this can be renewed quite easily. The vaporisers may be encrusted and require attention. But, on the whole, the depreciation charges should be no more—probably less—then those allowed for steam-generating plants. Most of the makers allow 10 per cent. depreciation, and this would seem to be a fair figure. In the comparative results for electricity *versus* suction gas which Messrs The National Gas Engine Company have worked out, it will be seen that that firm have allowed 10 per cent. for interest and depreciation, and something less than 1 per cent. for repairs and sundries. It would seem that the figure should be 5 per cent., or, say, for interest and depreciation together, 15 per cent. This means that, whereas they show a saving of £223 per annum by using suction gas instead of electricity at 1d. per unit, the saving on a basis of 15 per cent. as above would be £183—surely a substantial saving.

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[1] See also Appendix V.

Cost of Running.—Every endeavour has been made to obtain some reliable figures concerning capital, cost, etc., and the following figures are offered mainly as a guide. The following case is that obtained from Messrs Hornsby & Sons Ltd., of Grantham.[1]

We have assumed, for the purpose of illustration, a plant suitable for an average working load of 100 B.H.P., which plant would be capable of giving off 115 B.H.P. as a maximum.

A plant of this size, consisting of gas engine, suction gas plant, with all foundations, and the erection of the same, water vessels and all accessories, would cost about £850 complete. Assuming it would be required to run the plant 54 hours per week and 50 weeks per year, we then have a total power required per annum of 270,000 B.H.P. hours.

The annual cost of this running, taking the fuel used as being anthracite, 30s. per ton, the water costing 6d. per thousand gallons, and allowing for interest on the capital outlay, depreciation on same, labour, lubricating oil, stores, etc., would be about £330, this being made up as follows:—

Interest	£42	10	0
Depreciation	42	10	0
Coal	159	7	6
Labour	52	0	0
Lubricating oil, waste, and stores . .	10	0	0
Water	23	12	6
	£330	0	0

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[1] A section of the Hornsby plant is shown in fig. 5.

Dividing the above amount by 270,000, we have the cost per B.H.P. per hour as ·29d.

If the plant were run on coke, which could be obtained at 15s. per ton, the annual cost would be about £270 per annum, this being made up as follows:—

	£	s.	d.
Interest and depreciation . . .	£85	0	0
Coke	99	7	6
Labour	52	0	0
Lubricating oil, etc.	10	0	0
Water	23	12	6
	£270	0	0

Dividing this by 270,000, we have the cost per B.H.P. per hour as ·24*d.*

As regards the cost of labour given above, we have allowed for one man at £1 per week, but would point out that not more than one-third of his time would be occupied in looking after the plant.

Pintsch Estimates.—The following estimate has been supplied to me by the Power Plant Construction Company, and it is their calculation of the working costs of 1000 H.P. suction gas installation. The figures must, of course, be closely examined, and the reader, it is hoped, will be able to form some idea of the manner in which the costs are calculated. All of them are given as a guide rather than as certified figures; at the same time, it is only fair to add that there is no reason why these figures should not be considered a guide.

Costs of Installing in London.

(1) One suction gas plant of 1000 H.P. . . . . (When two plants of 500 H.P. each are installed, the price would be £400 more.)	£1,600
(2) Two gas engines of 500 H.P.	7,000
(3) Crane installation	300
(4) Water supply installation	500
	9,400

(In the case of sufficient water not being obtainable from a well or other source, the erection of a cooling vessel is required.)

(5)	Foundations	200
(6)	Cost of the building (5000 sq. ft. about 22 ft. high)	1,400
		£11,000

When the plant is working daily ten hours with the full load of 1000 H.P. for 500 days, or 3,000,000 H.P. hours in the year, the working costs are as follows :—

	£	s.	d.
Interest on the whole of the installation at 4 per cent.	£440	0	0
Depreciation on items 1–4 at 10 per cent.	940	0	0
„ „ 5–6 at 3 per cent.	48	0	0
Repairs, cleaning and lubricating materials	200	0	0
Attendance :—			
One mechanic to superintend the plant, 6s. per day	90	0	0
Three workmen, each 4s. 6d. per day .	202	10	0
Fuel $\frac{3}{4}$ lb. per H.P., therefore 3,000,000 by $\frac{3}{4}$, or 2,250,000 lbs. at 25s. per ton	1255	10	0
Oil for the engines, 1 oz. per 15 H.P., therefore $\frac{3,000,000}{15}$ or 200,000 oz. at 3d. per lb.	156	5	0
	£3332	5	0

The price of the dynamo is not considered herein : the efficiency of the same can be presumed at 92 per cent., so that there will be obtained 920 H.P., or 690 KW. net output.

The cost per H.P. hour is thus ·24 penny at the engine and ·26 penny at the switchboard.

The cost per KW. hour is ·35 penny at the switchboard.

The same firm have supplied me with the following calculation of the working costs of a 2500 B.H.P. suction gas installation, gas engine and dynamo:—

Costs of Installing in Germany.

	Marks or Shillings.*
(1) One suction gas plant of 2500 B.H.P., including reserve 800 B.H.P.	70,000
(2) Three gas engines of 800 B.H.P., each 86,000	260,000
(3) Crane installation	6,000
(4) Water supply installation	10,000
(In case of sufficient water not being obtainable from a well or other source, the erection of a cooling installation is required.)	
(5) Three dynamos of 550 KW., each 66,000	200,000
(6) Foundations	4,000
(7) Cost of buildings, 65 × 75 ft. (about 27 ft. high)	30,000
	580,000

When the plant is working daily ten hours with the full load of 2500 B.H.P. for 300 days, or 7,500,000 hours in the year, the working costs are as follows:—

	Marks or Shillings.
Interest on the whole of the installation at 4 per cent.	23,200
Depreciation on items 1–5 at 10 per cent.	54,000
" " 6–7 at 3 per cent.	1,020
Repairs, cleaning and lubricating materials	6,000
Attendance:—	
One mechanical engineer to superintend the plant, 7s. per day	2,100
Four workmen, each 4s. per day	4,800

---

* The value of a mark (Germany) is practically equivalent to an English shilling.

	Marks or Shillings.
Fuel ¾ lb. per B.H.P. hour, therefore 7,500,000 by ¾ lb. = 5,625,000, or about 2500 tons at 20s. per ton	5,000
Oil for the engines; 1 oz. per hour for 15 B.H.P.; therefore $\frac{7,500,000}{15}$ or 500,000 oz. at 3d. per lb.	7,810

The efficiency of the dynamo can be presumed at 92 per cent., so that there will be obtained 675 watts from 1 B.H.P. hour and from 7,500,000 B.H.P. hours as follows:—

$$7,500,000 \text{ by } 0{\cdot}675 = 5,062,500 \text{ KW.}$$

Therefore 1 KW. will come to

$$\frac{149,530}{5,062,500} = 0{\cdot}0295, \text{ or about } \tfrac{3}{8} \text{ penny per unit.}$$

Working Costs of Crossley Plant.—The following is a detailed account of the working costs of a Crossley plant installed at the New Arrol Johnston Car Co., Paisley. The plant consists of two electric-lighting type gas engines with suction producers, each driving a D.C. generator by belt.

The smaller engine is 40 B.H.P., has electric ignition, and is arranged to be run with town gas if required. The larger is 140 B.H.P. and has twin tube ignition, using town gas in the burners. Starting is effected by a gas-driven air compressor, running on town gas.

It is seldom possible for the student to obtain cost and commercial figures, and for that reason numerous examples are included. They may serve as a guide to firms who are contemplating the use of suction gas plants.

The figures include capital cost of all plant, foundations, and alterations to adapt existing buildings, but do not include mains from power-house to works. The running costs are derived from the power-house records up to the end of June 1906, readings of all necessary particulars having taken place every fifteen minutes.

Capital Expenditure.

40 B.H.P. engine, producer, piping, gas-bag, spares and producer covering .	£396	10	0
140 B.H.P. engine, producer, piping and producer covering	1068	0	0
Belts 8 in. and 18 in. laminated . .	54	0	0
Two-panel switchboard, watt meter and main switch	107	0	0
Cast-iron tank	135	0	0
D.C. generators (30 and 94 KW.) . .	278	0	0
Air compressor, receiving and starting gears	46	10	0
Foundations and floors	75	0	0
Inside cables, gratings, rails, furnishing and erection	50	0	0
Alterations to buildings, producer-house roof, etc.	105	0	0
	£2315	0	0

The smaller plant ran 54 hours weekly, the larger 112 hours. Each was cleaned once in 12 hours, the coal riddled out and picked being returned to hopper.

Interest and Depreciation.

Interest on capital (5 per cent. on £2315)	£116	0	0
Depreciation on engines, piping and tanks (5 per cent. on £1355·5)	67	16	0
Depreciation on producers and coverings (7½ per cent. on £290·5)	21	16	0
Depreciation on generators, switchboard, etc. (5 per cent. on £410)	20	10	0
Depreciation on belts, foundations, gratings, etc. (10 per cent. on £154)	15	8	0
Annual total .	£241	10	0

Average weekly output, 9500 KW. hours, 230 volts.
Capacity large set, 425 amps., small set 105.

Average output, large set, 330 amps., small set 70.
Load factor therefore is 70 per cent.

Average coal per week (anthracite doubles at 15s. 6d.)	14,500 lbs.
Average coal per week (KW. hour)	1·53 lbs.

Stand-by Losses.

Two producers at week-end	450 lbs.
Small producer, 5 nights	250 lbs.
Coal consumption per week for stand-by	700 lbs.
Average coal for power (14500–700)	13,800 lbs.
,, per KW. hour for power	1·45 lbs.

Labour.

One man at 24s., one at 22s. (night shift), and relief at 4s. per week, £2, 10s.

Water.

In large scrubber and boiler, per hour	260 galls.
,, small ,, ,, ,,	159 ,,
,, exhaust valve of engine	112 ,,
Total per week	40,200 galls.
Water per KW. hour	4·24

Price per 1000 galls. = 4d.

Oil.

Total for all purposes per week	3·6 galls.
,, ,, ,, KW. hour	·00038 galls.

Average cost 1s. 8d. per gall.

Coal Gas.

In starting engine and burner of 140 H.P. engine per week	1000 cub. ft.
In starting engine and burner of 140 H.P. engine per KW. hour	·105 ,,

Repairs and renewals—say £15 per annum.

Costs per KW. Hour, assuming a working year of 49 *weeks.*

	Penny.
Anthracite $\frac{1{\cdot}53 \times 15\text{s. } 6\text{d.} \times 12}{2240}$	·1270
Coal gas $\frac{1000 \times 2 \times 12}{1000 \times 9500}$	·0026
Wages $\frac{50\text{s.} \times 12}{9500}$	·0630
Water $\frac{40200 \times 4\text{d.}}{1000 \times 9500}$	·0170
Oil $\frac{3{\cdot}6 \times \frac{1}{8} \times 12}{9500}$	·0076
Depreciation and interest $\frac{241{\cdot}1 \times 240\text{d.}}{49 \times 9500}$	·1250
Repairs and renewals $\frac{15 \times 240}{49 \times 9500}$	·0077
	·3499

Total cost of 1 KW. hour at the switchboard = ·35 penny.

This example has been included with the object of showing the various sources of loss that must be taken into account in working out the cost per H.P. hour, and the manner of dealing with them in the course of the working out.

Comparative Figures—Suction and Coal Gas.—In dealing with the subject of economy there are many difficulties, and it is certainly not my intention to make any *ex cathedra* statements upon such a matter. Human nature is very much the same in politics or in any rival commercial concern. The opposition is always "agin the Government," and the town gas engineer must not be expected to regard with favour any innovation which is likely to lower his load. It would be quite possible for me to present you with figures obtained from actual practice showing how much per annum was saved when a suction gas plant replaced a steam engine, and the figures would possibly astonish you. But were I so disposed, I might easily fail to mention that the steam engine was perhaps an old Watt-type, beam-working engine, on say 5 lbs. pressure, as they did eighty years ago, and of very much more historic interest than of practical value at this time. Clearly that would not be a fair case, but I might be able to persuade you by using such figures that there was no argument on the other side. Similarly, I might take you and show you an up-to-date suction gas plant and gas engine which has replaced, shall we say, a slide-valve gas engine with a tube ignition, and probably a very leaky valve, and I could present you with remarkable figures. But if I had left out the suction gas plant, and had put in a new high-speed balanced and magneto-ignition gas engine, I could have told a cheerful story when using town gas. And therefore, much as I should be delighted to enter into and examine different cases, I think it wisest only to show you how the point of view will affect estimates. I will merely quote two cases which will show clearly what I mean. I have carefully studied all of the papers on this subject by Mr Hugh Campbell, and a few weeks ago was looking through some of his estimates.

While preparing these lectures I have been in correspondence with all the leading makers of suction gas plants and am indebted to them for much information. Simultaneously, I came across some remarks by the gas engineer of Oldham, Mr T. Duxbury, from a recent Presidential Address to the Manchester District Institution of Gas Engineers. These remarks I have quoted at length:—

"The scare created some two or three years ago by the introduction of suction gas for motive power is now beginning to find its level; and I still hold to the opinion I expressed at the annual meeting of this Institution a year ago—that, 'if we produce a good coal gas at 2s. per 1000 cub. ft., there would be little fear of being knocked out of the market by suction gas.' Since last year I have interviewed several suction gas users in order to ascertain its actual cost both per 1000 cub. ft. and per 1 B.H.P.; but I have, so far, been unsuccessful, as nobody seems to keep an exact record of every item of cost; in fact, it does not seem to be known what it really does cost. I have therefore endeavoured, by the aid of a suction gas friend, to arrive at the cost per B.H.P. with a fair-sized gas engine running 10 hours per day. This engine is stated by the makers to be 45 B.H.P. with suction gas. Anthracite has been taken at the present price—namely, 34s. per ton (which was formerly only about 20s.). I have included the cost for town's water, and the labour required for cleaning out the generator, etc. as often as it is necessary, the labour for periodical inspections of the plant during the day, labour required for extra cleaning of piston, valves, etc. of gas engine caused by suction gas being dirtier than town's gas, and also the repairs and maintenance of plant, interest and depreciation on capital outlay. I have made the liberal allowance of 20 cub. ft. of coal gas per B.H.P.; and I have ample margin when I say that coal gas at 2s. per 1000 cub. ft. is cheaper than suction gas.

Estimated Cost of Suction Gas with a Plant in actual working for the past twelve months.

	Decimals of a Penny.		
Anthracite coal, 1·6 lbs. per B.H.P at 34s. per ton	0·29	per B.H.P.	
Town water used, 6·5 gallons per B.H.P. at 1s. 2d. per 1000 gallons	0·09	,,	
All labour as stated above	0·14	,,	
Repairs and maintenance of plant, etc.	0·14	,,	
Interest and depreciation on capital outlay	0·14	,,	
Cub. feet of town gas at 2s. for starting engine, etc.	0·05	,,	
	——		0·85d.
Cost with coal gas at 2s. per 1000 cub. ft., allowing 20 cub. ft. per B.H.P.	0·48		
Repairs and maintenance of gas engine	0·05		
Interest and depreciation	0·05		
	——		0·58d.

Cost of suction gas	0·85d.	per B.H.P.	=	£310	per annum
Cost of coal gas	0·58d.	,,	=	210	,,
	——				
In favour of town gas	0·27d.	,,	=	100	,,

"I have made a number of tests of suction gas, and find that the gross calorific value of this gas varies from 150 to 160 B.T.U.

with an average of 155 B.T.U., as against 600 B.T.U. for Oldham quality coal gas, and higher with a mixture of carburetted water gas, so that for power purposes coal gas has four times the calorific value of suction gas. In other words, suction gas produced on the basis of 6d. per 1000 ft. (at which price it is not made by the general user) is equivalent to 2s. per 1000 cub. ft. for coal gas." This is Mr Duxbury's estimate.

Now let me turn to an estimate by Mr Hugh Campbell for an engine of about the same size, from which I will draw your attention to one or two facts. Mr Campbell estimates the coal at 17s. per ton. The coal gas manager says it costs 34s. per ton. Mr Campbell estimates water at 6d. per thousand gallons and says that 3 gallons per H.P. are required. But Mr Duxbury says that the town water costs 1s. 2d. per thousand gallons, and that 6·5 gallons per B.H.P. are required. Consequently Mr Campbell's estimate in pence for B.H.P. per hour for water is just about one-sixth of that by Mr Duxbury. There is a great difference in the estimates of repairs, interest, and depreciation, but they agree fairly well on labour; but when we come to sum up, Mr Campbell shows a saving of £140 per year by using suction gas, and Mr Duxbury a saving of £100 a year by using town gas. Probably the truth of the statement varies according to the local conditions. Statistics can usually be compiled to prove a case. You will remember that Mark Twain tells us that when he had such a lot of travelling to do, he was frightened at the number of deaths resulting from railway accidents. In looking into the matter, he found that if he were to attend to his statistics the rest of his life would be uncomfortable, for an alarming number of people died in bed, and therefore he could argue that it was quite unsafe to retire to rest.

The following are the details of the estimate above referred to, and are given by Mr Hugh Campbell.

Estimated comparative Costs of running Gas Engine on Town Gas and Suction Gas Plant.

Basis of calculation, town gas 2s., anthracite coal 17s.
B.H.P. of engine, 80 B.H.P.

Average, B.H.P., 50.
B.H.P. hours worked 140,400 per year (54 hours × 52 weeks).

Total Cost.

	Suction Gas from Anthracite Coal.			Town Gas.			Pence per B.H.P. per hour.	
	£	s.	d.	£	s.	d.	Coal.	Gas.
Fuel	53	5	6	252	14	0	·091	·432
Water, 3 gallons per H.P. at 6d. per 1000	10	10	3				·018	
Two per cent. repairs, 5 per cent. interest, and 5 per cent. depreciation	72	0	0	54	0	0	·123	·093
Oil and stores	20	0	0	15	0	0	·034	·026
Attendance	75	0	0	52	0	0	·128	·089
	230	15	9	373	14	0	·394	·640

Saving effected by suction plant = 38 per cent.

For price of gas at equivalent value . .	£230	15	0
Less repairs, etc.	121	0	0
Total nett cost of gas 10·42d. per 1000 =	£109	15	0

Similarly :—

Coal at 17s. = gas at 10·42 pence per 1000.
Coal at 20s. = gas at 11·32 „ „
Coal at 24s. = gas at 12·51 „ „

The above figures are based on the following consumptions :—

Anthracite, 1 lb. per B.H.P. per hour.
Town gas, 18 cub. ft. per B.H.P. per hour.

FIGURES OBTAINED AT DUNBAR.

Mr G. Evetts mentions the following case of a 30 B.H.P. engine at Dunbar which was used both with suction and town gas. The totals are for one week in each case :—

Suction Gas.

Five cwts. of common anthracite per day at 25s. per ton	£1	15	0
Attendance, 1 man at 21s. 6d.	1	1	6
Water at ·016d. per B.H.P. hour	0	2	3
Interest and depreciation 10 per cent. on, say, £230	0	8	9
Total per week	£3	7	6

Town Gas.

The same engine used 380 cub. ft. of town gas per hour.

Town gas at 56 hours per week, at 3s. 4d. per 1000 cub. ft.	£3	10	9
Interest and depreciation on £135 (10 per cent.)	0	5	0
	£3	15	9

Here, he says, it is to be noted that anthracite is rather cheap, though a large quantity is used, while the town gas is very high in price. Making these corrections there is not much difference in costs per week. Mr Evetts gives, as a general rough rule, that suction gas is equivalent to town gas at 1s. 9d. to 2s. per 1000 cub. ft. This, of course, is largely affected by local considerations.

It should, of course, be noted, that the whole of the pay of a man for the week is put down against the suction plant. This is quite correct if the man does nothing else, but, as a rule, he would be employed to do other work in addition, as a gas plant of such a size would not take up nearly the whole of his time. In fact, it is usual to charge one-quarter of the man's time to the gas plant. This would bring the cost of the suction plant down to £2, 11s. 5d. per week, and would give a substantial saving in favour of the suction plant.

As electricity is also a formidable rival to suction plants for small power units, I will now give a number of figures from various sources, comparing the costs of these three methods of power production.

The following is an extract from the *Journal of Gas Lighting*, which one scarcely expects to be biassed in favour of suction gas plants. It is, of course, well known as a fair-minded technical periodical. The estimate runs:—

" '**Electricity, Coal Gas, and Producer Gas, its Relative Cost for Power,**' by H. J. Ibbotson, of Newport, I.W.—By the courtesy of Messrs Mew, Langton & Co., brewers, of Newport, (I.W.), I have been furnished with the following interesting figures relating to the difference in cost of power between coal gas, electricity, and producer gas generated in a suction plant. The difference between coal gas and electricity does not add anything to previous information on the matter; but the low cost of the producer gas is somewhat startling, and indicates a keener form of competition than is generally anticipated. The comparison is of considerable value, as in each case the test has extended over a period of 90 days. The load has been, as near as possible, uniform; and every care has been taken in obtaining reliable data.

"The gas-engine made by Messrs Tangye (J.S. size) was fixed in 1902, and is capable of developing 35 effective horse-power and 40½ indicated horse-power, with coal gas, at 180 revolutions per minute. With producer gas, the maximum effective horse-power is 29 and the indicated horse-power 35. The motor was supplied by the Edmundson Electric Corporation, and is marked 'volts 480, amps. 52, revs. per minute 700.' The current for the motor was supplied on the maximum demand system; and the termination of the 90 days' trial resulted in a charge of 1800 units at 4d. and 22,175 units at 1d.—*i.e.* a total of 23,975 units, at an average cost of 1·225d. per unit. The machinery consists chiefly of several large drums used in the process of malting, and revolving very slowly. The brake horse-power is taken at 18; and though this may have been subject to slight variation, the comparison cannot be seriously affected, as in the following statement the cost per brake horse-power per hour is calculated on the average daily consumption.

	Average Consumption.	Rate.	Cost per diem.	B.H.P.	Consumption per B.H.P.	Cost per B.H.P. per hr.
			s. d.			
Electricity	266·3 units	1·225d. per unit.	27 2·4	18	·816 unit.	·755d.
Coal Gas	7·200 cub. ft.	3s. per 1000 cub. ft.	21 7·2	18	18·66 cub. ft.	·600d.
	cwt. qrs. lbs.					
Producer Gas	4 1 24	22s. per ton.	4 10·9			
	anthracite	Extra labour	1 0			
			5 10·9	18	1·157 lbs.	·164d.

"It will be seen that the extra labour is taken at 1s. per day of 24 hours. This fairly represents the cost of charging the generator and raking out the ashes, as the plant is left unattended for periods of four hours. The generator has only been in use for four months, and has been worked with unskilled labour. It is believed that, with further experience, a slight reduction in the amount of anthracite used will be obtained. It will be noted that the engine when working with coal gas was only developing about half its maximum effective horse-power, while with the producer gas the load could be increased by about 11 horse power. In the case of the electric motor there is a much smaller margin, as this was fixed at a later date than the gas engine, and when the power required was more accurately known.

"The trial shows that one Board of Trade unit of electricity is equal to 27¼ cubic feet of gas; but, in connection with this matter, it should be noted that the sale of gas at the special rate of 3s. per 1000 cubic feet for power is a much more satisfactory commercial transaction than the sale of electricity at 1¼d. or any other price per unit in the Isle of Wight. The producer gas plant has not been in use long enough to enable the cost of maintenance or depreciation to be ascertained; but if this is balanced against the increased efficiency that should result with more familarity of the plant, it is shown that the cost of working is cheaper than coal gas at 10d. per 1000 cubic feet.

"The calorific power of the producer gas is stated as being from 140 to 150 B.T.U. per cubic foot. I regret that there is no information as to the heat value of the coal gas; but as the quantity consumed per brake horse-power was only 16·66 cubic feet, this must have been about normal."

"National" figures for Cost.—The following case is put forward by the National Gas Engine Co. as a comparison between town gas, suction gas, and electricity:—"Great claims are often made by electrical engineers and others as to the substantial advantage of taking current from a public supply instead of power users employing gas engines. Users should remember, however, that current is very seldom offered under any conditions at less than 1d. per unit for power, whilst lighting is charged at a higher rate. The following analysis shows, in a typical case, what are the comparative costs of driving a factory with electricity at 1d. per unit taken from the public supply, as against a suction gas installation doing the same work. We have taken the cost of a small user requiring 40 B.H.P., but it will be appreciated that with a larger demand the advantage is still more in favour of suction gas." The case is now presented for the reader to judge for himself. The problem is somewhat involved, but most interesting.

Cost of Electric Driving.—One unit of electricity is equal to one hour's output of 1⅓ B.H.P. In other words, one B.H.P. developed over an hour is equivalent to ·746 unit. In the case of electricity taken from the public supply, however, the current is invariably measured at the meter before it passes into the motor, and, due to the internal resistance of the latter, part of the current which is used is absorbed in the motor itself. The actual efficiency of a good electric motor is about 85 per cent., so that for every B.H.P. developed at the pulley of the motor, and available there for useful work, the actual current measured at the meter is equivalent to ·88 unit. In the example under consideration, therefore, a demand of 40 B.H.P. corresponds to 35·2 units consumption at the meter per hour. On the basis of 53 hours per week and 50 weeks per year (2650 hours per annum), the annual consumption of current would be

$$35{\cdot}2 \times 2650 = 93280 \text{ units per annum.}$$

At 1d. per unit this represents a total charge for current equivalent to £389 per annum. Add to this the rent of the motor, £20 per annum, and the total cost of electric driving is £409.

Cost of Working with Suction Gas.—We here make the reasonable assumption that gas coke is procurable at 12s. a ton, and that the all-round consumption, including stand-by losses, is the usual figure of 1½ lbs. per B.H.P. per hour. The total consumption per annum of fuel will be—

$40 \times 1\frac{1}{2} \times 2650$ . . . . . = 67 tons.
The total oil consumption per week = 14 pints.

The total oil consumption per annum will be—

$14 \times 50 =$ say 90 gallons.

Water consumption = 3000 gallons per week = 150,000 gallons per annum.

The total cost of the engine and plant fixed and ready for work will be approximately £360. Add to this, for foundations, etc. £40, and the total capital expenditure will be £400. The total annual charges can therefore be put down as follows:—

Interest and depreciation, 10 per cent. on £400 =	£40	0	0
Repairs and sundries, average over 10 years (say)	5	0	0
Fuel, 67 tons of coke at 12s. a ton =	40	0	0
Oil, 90 gallons at 1s. 6d. =	6	15	0
Water, 150,000 gallons at 9d. =	5	12	6
Attendance, one-half man's wages at 20s. per week =	25	0	0
	£122	11	6

The difference between the cost of electricity and the cost of suction gas, taking all charges into consideration, equals £286, 8s. 6d. per annum. In other words, the gas-engine plant will, as a result of the saving effected, pay for itself in less than eighteen months, and thereafter, compared with the cost of electricity, there is a clear saving to the user of over £5 a week.

In the foregoing case we have taken a comparison of where a gas engine is connected up to a line shaft, as against an electric motor driving the same. The second instance is where a large amount of current is required in a factory, and is either to be generated by the user himself or taken from the public supply.

For an average electrical demand of 40 B.H.P., an engine of about 60 B.H.P. would be required in the majority of cases. The capital expenditure would approximately be as follows:—

60 to 70 B.H.P. electric type engine coupled direct to dynamo, all complete and ready for work	£900	0	0
Foundations, etc.	50	0	0
	£950	0	0

The annual charges under these new conditions would be as follows:—

Interest and depreciation, 10 per cent. on £950	£95	0	0
Repairs and sundries, average over 10 years (say)	7	10	0
Fuel	45	0	0
Oil	7	10	0
Water	6	0	0
Attendance, half man's wages at 20s. a week	25	0	0
	£186	0	0

Total units developed = 93280.
Cost per unit . . = ·47d.

It will be realised that this is a very low figure indeed for a 40 H.P. demand. The saving in this case, as against taking current from the public supply at 1d. a unit, will be £223 per annum. We might here point out that we have found, as a result of experience, that the actual charges when current is taken from the supply is always in excess of the estimate, and conversely with gas power. That is the statement of the Company.

Saving effected by use of Suction Gas as against Town Gas.—Cases frequently arise in which power users have already got a gas engine, and desire to know what the saving would be if they put down a suction producer. Taking the case again of an engine giving out an average of 40 B.H.P., the following will show a comparison of the costs:—

Suction Gas—

Approximate cost of gas plant fixed and engine altered for use with suction gas = £150 0 0

Interest and depreciation, 10 per cent on £150	£15	0	0
Repairs and sundries	5	0	0
Fuel	40	4	0
Oil	6	15	0
Water	5	12	6
Attendance, half a man's wages at 20s. a week	25	0	0
	£97	11	6

Cost of working with Town Gas—

Repairs, etc.	£4	0	0
Fuel (town gas at 2s. per 1000)	190	16	0
Oil	6	15	0
Water	1	5	0
Attendance, quarter of a man's wages at 20s. a week	12	10	0
	£215	6	0

Saving as between suction gas and town gas = £117 14 6

per annum. This saving is sufficient to pay for the suction plant in eighteen months. That is the above firm's estimate.

The foregoing example shows how in ordinary cases a very great saving can be effected by introducing a suction plant where town gas is already in use.

Mr Moon, at the close of the lectures, gave the following figures for the comparative cost of running on town gas, suction gas, and electricity, based upon the prices now ruling in the East End of London.

Town gas, 2s. 5d. per 1000 cub. ft. (less 10 per cent.). Labour, 25s. per week. Anthracite, 35s. per ton. Water, 9d. per 1000 galls. Treating effluent from scrubbers, 3d. per 1000 galls.

For a 40 B.H.P. plant running for 60 hours per week, he gives

40 H.P. of electricity at 1d. per unit . .	£7	10	0	per week.
Town gas (18 cub. ft. per B.H.P. hour) .	5	9	0	,,
Suction gas { 1 lb. anthracite per B.H.P. hour 2 galls. water ,, ,, }	4	5	6	,,

With electricity, it should be noted that there are no stand-by losses or depreciation, as, although the motors require repairs, these can be treated as distributing machines, and not as prime movers like an engine.

It appears, then, from these figures that, given normal conditions and prices, the suction plant shows a substantial saving over any other means of power production—at any rate, where small units are employed. With large powers, the bituminous plant, with recovery of bye-products, is more economical, and is consequently used to a greater extent.

THE GAS ENGINE.

As the producer plant depends entirely for its output of mechanical work on the engine which it supplies, a few remarks on the latter may not form an inappropriate ending to this series of lectures. A most important point that arises in connection with the engine is the quantity of gas admitted into the cylinder at each stroke, as the power of the engine depends on this. It is worth while to consider, then, by how much the weight of gas in the cylinder is diminished by using a suction plant, as compared with that admitted by a pressure plant.

Quantity of Gas in Engine with Suction Plant.—It should be remembered that the volume of the gas varies with the pressure and temperature ($PV = KT$), assuming that the temperature of gas supplied to a gas engine is constant at, say, 60° F. If the gas is admitted at atmospheric pressure to the engine cylinder, that pressure is 14·7 lbs. per sq. inch. But with a suction plant it is admitted at about $1\frac{1}{2}$ lbs. below atmosphere, or say 13·2 lbs. per square inch absolute. This is at the beginning of the stroke.

At the end of the suction stroke the pressure should be about ½ lb. per square inch below atmosphere. At these two points, therefore, the weight of the gas admitted, as compared with that admitted by a pressure plant, is

$$\frac{13\cdot2}{14\cdot7} \text{ or } 90 \text{ per cent., and}$$

$$\frac{14\cdot2}{14\cdot7} = 96\cdot6 \text{ per cent.}$$

The average figure has been improved upon. Mr Clerk, in his book *The Gas Engine*, puts it very clearly on page 308 of the last edition at this date.

It should also be remembered that a certain burden is thrown on the engine to produce the suction, and is different when it takes gas from a bag under pressure.

What the Diagram shows.—The indicator is equally useful with the gas engine and the steam engine, but far more difficult to operate with the former than with the latter. Still, it is possible to discover what is happening within the cylinders, and especially useful is it to compare several cards taken from the same engine. It must be remembered, one of the great things which affects efficiency of the gas engine is the compression, which tends to greater efficiency. But there are several causes which tend to lower the mean effective pressure on the diagram, and these causes have been classified by Professor C. E. Lucke in three classes. In class 1 are those that change the weight of the cylinder charge; in class 2 is the improper treatment of full charges; and in class 3 is the improper treatment of partial charges. Considering the first class, we find that, according to the Professor, the weight of charge may be lessened by—(1) too small an opening in the suction passages acting throughout the whole or a part of the stroke; (2) improperly set valves; (3) too heavy a spring on an automatic suction valve; (4) too small a valve diameter; (5) too small a valve-lift; (6) very crooked passages; (7) governor action; (8) too much back pressure, preventing entrance of new mixture; (9) sudden increase of back pressure, due to exhaust of one cylinder which is just beginning to exhaust blowing back into another cylinder whose exhaust is just closing; (10) heating of incoming gases by burnt gases in clearance or hot passages; (11) too high a speed; (12) improper capacity of suction chamber in two-cycle engines; (13) improper cam curves, or proper cam curves improperly set. In the second class the improper treatment of full charges may be brought about by—(1) leaks; (2) improper mixture, giving a slower rate of propagation for the same piston speed, making a flat-top diagram; (3) proper mixture with too high a piston speed; (4) too early ignition; (5) too late ignition; (6) improper mixture and ignition together; (7) improper release of gases when too early; (8) not the best compression pressure; (9) poor form of clearance or breech end. The third class, by the double action of the first two, will produce results doubly intense, and mixtures may be too slow in burning, ignition wrong, and only partial changes present; so, with all these actions, the mean effective pressure can only be very low.

The study of the indicator diagram from the plant tested in the Royal Agricutural Society's competition at Derby enables us to see at a glance that the indicator diagram can really give us an idea of the quality of the gas used. From the report, it appears that the National plant developed the largest B.H.P. per cubic foot of piston volume, and this leads us to assume that this producer was capable of producing gas of a better quality, and of maintaining that quality continuously, than the competitors. Although this engine was quite up to its power, the explosion pressures were lower than those of the competitors.

In reply to my inquiry with regard to these trials, Messrs Crossley write as follows:—"With regard to the Derby trials, whilst it is quite true that the maximum pressure on the indicator cards are higher than those of the National Company, yet we do not consider it so serious as they make it. The reason they had a lower coal consumption than ours was not because of this point, nor yet because of the quality of gas from the producer, but because the engine was running far too slow for the plant. If this engine had been run to give 18 H.P. instead of 15, the coal consumption would have been well under 1 lb.; indeed, on tests made since the Derby trials, we have obtained, under corresponding conditions, nine-tenths of a pound of coal consumption per B.H.P. per hour, including all stand-by losses. With regard to the mean pressure obtained from the engine, this had nothing to do with the quality of the gas at all. You will understand that on the weight of gas entering the cylinder depends the power obtained, and the settings of the valves of the engine were expressly set to get this result. As we have above pointed out, the mistake we made was not running the engine at a higher power, but, having entered it at such a low power, we had to comply with the conditions not to exceed the guaranteed power by more than a small quantity, otherwise we would have been disqualified, and the gascock being checked, gave the lower mean pressure referred to."

The Pressures and Temperatures of the Gas Engine.—It may be useful to the reader if, at this point, I give some of the values likely to be obtained for the pressures in the cylinder at various parts of the cycle. As we have seen, the pressure at suction is about 1½ lbs. per sq. in. below atmosphere, or 13·2 lbs. absolute on this area. The maximum pressure obtained on combustion, a little after passing the dead centre, is the most important for designing purposes. It is usually taken, for the average engine, at about 350 lbs. per sq. in. If a pre-ignition occurs, however, it it may rise to 450–500 lbs., and so the working parts have to be designed strong enough to stand this pressure. The compression pressure is also important, as on this depends the economy of the engine. It averages about 85–100 lbs. per sq. in., though a compression of 200 lbs. has been used by Professor Burstall on a "Premier" engine. The mean pressure for an engine of the above kind would average about 85 lbs per sq. in.

It is most important to be able to measure the temperature of the gas in the cylinder at some part of the cycle. If the temperature at some suitable point be known, that at other points can be calculated from the laws of gases. Professors Callendar and Dalby have devised a very ingenious method of measuring the temperature in the cylinder at any part of the cycle.[1]

It is impossible to use a platinum thermometer continuously exposed to the hot gases in the cylinder, as, if it is strong enough to resist the pressure of the gases, it is too thick to follow the variations in temperature with sufficient rapidity; if it is thin enough to do this, it is not strong enough to withstand the pressure, and breaks before a sufficient number of observations can be taken. The Professors, therefore, used a special admission valve, bored out to receive a smaller valve. This resistance thermometer (platinum) was contained within this small valve, which was operated by a special cam, which could be set to expose the thermometer to the hot gases during any part of the cycle, and the valve was so shaped as to protect the filament from mechanical stresses as completely as possible, without introducing disturbing elements. The electrical connections were made so that the temperature at one instant only was measured; and by altering the contact pieces that regulated this instant, the temperatures at various points of the cycle were found. The suction temperature was found by them to vary from 95° C. on light load trials to 125° C. on full load, the air temperature being 20° C. and the jacket temperature 25° C.

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[1] *Proc. Roy. Soc.*, Oct. 8, 1907.

The engine used was a 10 H.P. Crossley, with a cylinder of 7-ins. diameter and 14-ins. stroke. In one of the trials the maximum explosion pressure was about 370 lbs. per sq. in., and the corresponding temperature 2250° C., or higher than the melting point of platinum.

The following results were obtained from a test on a 15 B.H.P. Crossley gas engine, in the engineering laboratory at King's College, London. The speed was regulated by a centrifugal governor, which actuated a "hit and miss" arrangement, cutting off the gas supply when the speed exceeded a certain limit and admitting it more freely when the speed fell. Town gas was used.

The log sheet used on such a trial resembles that shown on p. 159, wherein are recorded the readings taken for the trials to determine the calorific value of coal gas. Columns must be ruled out for the following data to be recorded, viz. time, meter readings (which include quantity of gas used on the temperature, and pressure of the gas at the inlet and outlet of the meter), the number of pounds of water used for cooling purposes, and the temperatures of the water entering and leaving the water jacket of the engine cylinder, the number of revolutions, and the number of explosions.

The weight of gas used may be calculated as shown in Appendix I. Part I. From the indicator diagram the temperatures of the gas at the various points along the stroke can be calculated. Until recently it has been the usual practice to estimate that the temperature of the gas at the commencement of the stroke is a mean of the temperatures of the gas in the meter and temperature of the outlet of water jacket.

It is not possible to give, in the space available, a fully-worked-out gas engine trial. A gas engine indicator diagram is, however, included by request of one of the men who attended the lectures. The temperature at the highest pressure (absolute) is estimated, in this case, to be 2068° F., and the temperature of the gas at exhaust is estimated to be 800° F. The maximum pressure was 254 lbs. per sq. in.

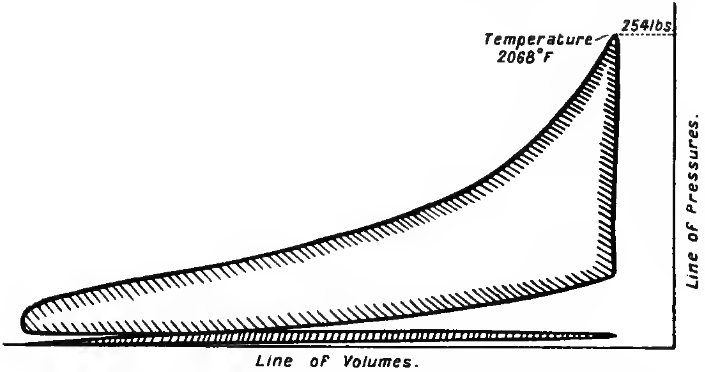

FIG. 34.—Temperature of Explosion as calculated from Gas Engine Diagram.

It is greatly to be regretted that it is not possible to elaborate upon the subject of gas engines. There are, however, many excellent books upon the internal combustion engine, including one by Professor Robinson of Nottingham, entitled "Gas and Petroleum Engines." There is therefore ample opportunity for the man who wishes to study the subject to do so. The object of these lectures has been, chiefly, to describe suction gas producers. It may be possible at some future date to give further lectures dealing with internal combustion engines.

The Appendices have been added at the request of certain correspondents, who are thanked for their very kind suggestions.

Conclusion.—It may be said, in conclusion, that the suction gas plant is the natural outcome of a demand for cheap plants of small power, and, as they are but a modification of the ordinary pressure type, there is little to be said about them that does not hold good for the other type.

As we have seen, the plant offers resistance to the flow of gas, and so the best design is that in which the resistance is reduced to a minimum. The design should be such as to reduce as much as possible the pulsating effect due to the intermittent pull of the engine, and to keep the draught on the producer as steady as possible. There should be the least possible tendency on the part of the air to lift the fuel, so that dust can be carried into the gas, and all short-circuiting, on the part of the air and steam should be avoided by designing the producer so that the distribution shall be as uniform as possible. Cheapness should not be the first consideration, but sound workmanship should be employed throughout, when the cost of maintenance will be a minimum, and very little trouble experienced in working. If these conditions are observed, the suction plant should be able to put up a hard fight against all other small power generators, in which connection there is open to it a great field of usefulness.

All of the figures of cost, capital expenditure, and running expenses which are quoted above require that care should be taken by the reader to fully understand the manner in which such figures are obtained. An endeavour has been made to show how very important it is that accurate running costs should be carefully recorded, although it is unfortunately true that such costs very seldom are kept by users of suction gas-plants. Consequently many of the figures quoted are those supplied by makers, but at the same time extreme cases have been contrasted (see pp. 136, 137) in order to show how essential it is to analyse statements made by opponents and those who naturally advocate the use of suction gas plants. It is hoped that interest in the commercial aspect of power production will continue, and that improvements in design of all power production machinery will lead to a reduction in the cost of generators.

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[1] This has been compiled from various sources. The author would be glad at all times to receive intimation of new literature on the subject.

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APPENDICES.

APPENDIX I.—Part I.

DETERMINATION OF CALORIFIC VALUE OF COAL GAS.

The Junkers Calorimeter.—The Junkers calorimeter is essentially a small boiler, to which as much of the whole heat of combustion of a gas flame as possible is transferred and measured. It consists of a hollow cylindrical vessel A, through which water is continuously passed. A large Bunsen burner is placed inside this hollow cylinder. By passing a measured amount of water through the cylinder and noting the rise in temperature, we find the number of heat units absorbed by the water, and hence the calorific value of the gas.

Cold water passes from a tap to the reservoir D, constructed as shown, in order to keep the flow of water constant. The water passes down the tube E, which bends round in a **U** at G, and enters the calorimeter near the bottom at F. The water then passes up through the calorimeter to the top H. Thence it passes into another small reservoir J, from which it is conducted through an india-rubber tube into measuring flasks. There is a thermometer at F to measure the temperature of the water entering, and another at H to measure the temperature of the water leaving the calorimeter. The hot gases from the Bunsen burner B pass up inside the calorimeter to the top K, where they are deflected down through tubes L L passing through the water into a small chamber M at the bottom. Thence they pass into the atmosphere through flue N. The water produced by the combustion is drained off at O and carefully measured.

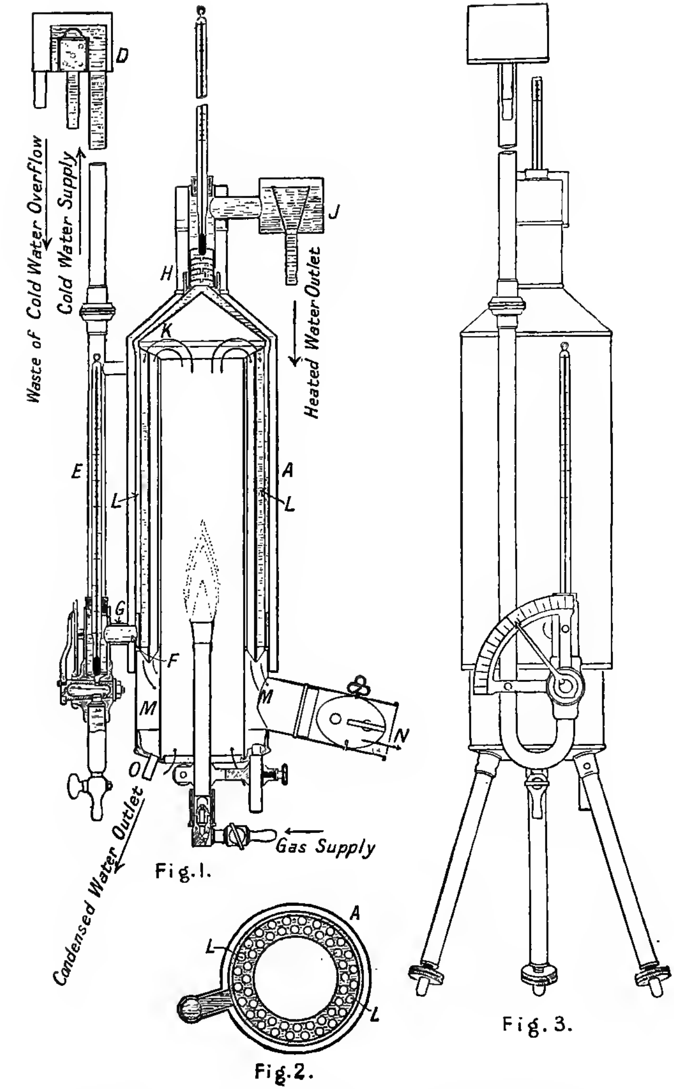

Fig. 1.

Fig. 2.

Fig. 3.

Fig. 35.—Junkers Calorimeter for testing Calorific Value of Gas.

The following account of a series of tests made to determine the calorific value of coal gas by the use of this apparatus will help to make the method of conducting such tests and working out the results more clear.

The pressure and temperature of the gas at inlet and outlet of meter was noted. From this we can find the weight. The volume of gas used was found by taking readings on the meter at beginning and end of test. The pressure at the burner was kept constant by a small gasometer, which was fitted with a manometer for indicating the pressure. We passed (in each case, except one) 10,000 c.c. of water through the calorimeter,

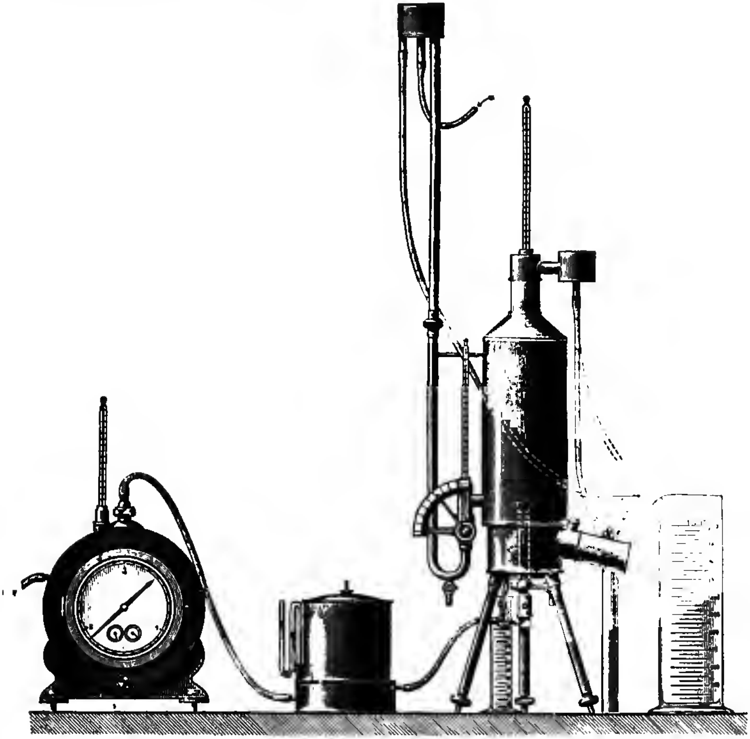

FIG. 36.—Junkers Calorimeter arranged ready for use.

collecting the water in two 5000 c.c. flasks. The water must pass through the calorimeter fast enough in order to prevent the temperature from getting too high. The rate at which water passes through is regulated by a valve at F. The temperature at which the products of combustion are discharged is made as nearly as possible equal to atmospheric temperature.

Our thermometers were graduated to ·1° C., but, by the help of the microscopes provided, we could estimate to ·01° C. Readings of temperature, pressure, etc. were taken every five minutes. The experiment was performed six times at six different temperatures of the outflowing water, so as to get a good average result. The thermometers used for the gas were in degrees Fahrenheit.

General expression for Calorific Value of Gas.

Let W = weight of gas used in lbs.
V = vol. of gas per lb.
v = actual vol. used.
P = pressure of gas used (absolute).
T = temp. of gas used (absolute).

Then $PV = KT$. K = difference between specific heat at constant pressure and that at constant vol. = 128·1 for coal gas.

Then volume per lb. $= V = \dfrac{TK}{P}$.

$$\therefore \quad W = \frac{v}{V} = \frac{vP}{TK} = \frac{vP}{128{\cdot}1 \times T}.$$

Let C = calorific value of gas (per lb.).
T_1 = initial temp. of water ° F. (average).
T_2 = final „ „ „
W_1 = weight of water passed through calorimeter in lbs.
w = weight of condensed water.
L = latent heat of evaporation of water.

Then
$$W \times C = W_1(T_2 - T_1) - wL.$$
$$\therefore \quad C = \frac{W_1(T_2 - T_1) - wL}{W}.$$

The following Table shows the log readings of six tests, each of which is then fully worked out.

No.	Time.	Gas.					Water.				Flue Temp. ° F.
		Pressure.		Temp. ° F.		Meter Reading Cub. ft. of gas.	Temp. ° C.		Vol. passed.	Vol. condensed.	
		In.	Out.	In.	Out.		In.	Out.			
1.	4·32	3·3″	8·25″	59°	60°	1·80	8·70	47·75	..	..	61°
	·37	,,	,,	,,	,,	2·36	8·72	47·71	..	..	60·5
	·42	,,	,,	,,	,,	2·88	8·76	47·65	5000 c.c.	61 c.c.	61
	·47	,,	,,	,,	,,	3·45	8·70	47·91	..	..	,,
	·52	,,	,,	,,	,,	4·20	8·68	48·40	..	..	,,
	4·57	,,	,,	,,	,,	4·49	8·70	48·76	5000 c.c.	..	,,
2.	2·2	3·2	3·1	55	55·5	·35	9·70	44·90	..	.	62
	·7	3·15	3·05	,,	55·6	·9	9·60	44·98	..	..	,,
	·12	3·1	,,	,,	,,	1·5	9·52	44·90	5000 c.c.	57 c.c.	61
	·17	,,	,,	,,	55·5	2·03	9·43	44·83	..	..	,,
	·22	,,	,,	,,	,,	2·56	9·38	44·78	..	..	,,
	2·25	,,	,,	,,	,,	2·85	9·33	44·60	5000 c.c.	..	,,
3.	2·43	3·15	3·1	55	55·5	−0·17	9·11	37·40	..	..	60
	·48	,,	,,	,,	55·4	..	9·08	37·41	..	..	,,
	·53	,,	,,	,,	55·5	·05	9·11	37·35	5000 c.c.	45 c.c.	,,
	·58	,,	,,	,,	,,	1·60	9·07	37·32	..	..	,,
	3·1	,,	,,	,,	,,	1·87	9·03	37·29	5000 c.c.	..	,,
4.	·7	3·35	3·30	59·5	60	−·96	8·73	33·58	..	..	61
	4·12	,,	,,	59	,,	−·40	8·75	33·70	..	40 c.c.	,,
	·17	3·30	3·25	,,	,,	·13	8·75	33·06	5000 c.c.	.	,,
	4·23	,,	,,	,,	,,	·76	8·71	33·80	5000 c.c.	...	60
5.	3·11	3·15	3·10	55·5	56	2·92	8·92	30·42	..	..	60
	·16	,,	,,	,,	,,	3·46	8·91	30·48	5000 c.c.	..	,,
	·21	,,	,,	,,	,,	4·00	8·90	30·60	..	35 c.c.	,,
	3·25	,,	,,	,,	,,	4·42	8·89	30·52	5000 c.c.	..	,,
6.	3·36	3·4	3·35	56·5	57	·65	8·77	25·63	..	..	59
	·41	,,	,,	57	57·5	1·20	8·70	25·68	5000 c.c.	..	,,
	·46	,,	,,	,,	58	1·78	8·72	25·73	5000 c.c.	53 c.c.	59·5
	·51	,,	,,	57·5	58·5	2·31	8·70	25·70	5000 c.c.		60
	·56	,,	,,	58	59	2·98	8·70	25·75	5000 c.c.	..	,,

Barometer 757 mm. of mercury.
These observations are now worked out.

Test 1. Total heat given up by gas = weight of water (final − initial temp.) ° F., 10,000 c.c. water weigh 22·04 lbs.

$$= 22{\cdot}04(48{\cdot}06 - 8{\cdot}71)\,\frac{9}{5} = 22{\cdot}04 \times 39{\cdot}35 \times \frac{9}{5}$$

$$= 1560 \text{ B.T.U.}$$

In this is included heat of combustion = condensed water × 696

$$= \frac{61 \times 966}{454} \qquad (454 \text{ gms.} = 1 \text{ lb.})$$

$$= 130 \text{ B.T.U.}$$

∴ Heat available or given up by gas = 1560 − 130 = 1430.

Now $PV = cT$, where P = absolute pressure per sq. ft. (lbs.).
T = absolute temp. ° F.
$c = 128{\cdot}1 \ (= K_p - K_v)$.
V = vol. of 1 lb. of gas.

$$\therefore \ V = \frac{cT}{P} = \frac{128{\cdot}1\{461 + 59{\cdot}5\}}{14{\cdot}7 \times 144 + 16{\cdot}9}$$

$$= \frac{128{\cdot}1 \times 520{\cdot}5}{2115 + 16{\cdot}9}$$

(Where 14·7 × 144 lbs. = Atmospheric pressure per sq. ft., and 16·9 lbs. = water pressure per sq. ft. This latter = $\frac{3{\cdot}25}{12} \times 62{\cdot}5$ lbs. per sq. ft.

$$= 31{\cdot}35 \text{ cub. ft. per lb.}$$ (3·25 = pressure on gas in inches of water),

and Vol. used = 4·49 − 1·80 = 2·69 cub. ft.

$$\therefore \text{ Weight used} = \frac{2{\cdot}69}{31{\cdot}35} \text{ lbs.} = {\cdot}0859 \text{ lb.}$$

$$\text{Calorific value} = \frac{\text{Heat given up}}{\text{Weight of gas used}}$$

$$= \frac{14300000}{85{\cdot}9}$$

$$= 16700 \text{ B.T.U. per lb. of gas.}$$

$$\text{or} \qquad \frac{16700}{31{\cdot}35} = 534 \text{ B.T.U. per cub. ft. of gas.}$$

The average final and initial temperatures and pressure of gas are taken, 966 = latent heat of water at 212° F. (atmospheric pressure).

Total pressure on gas = atmosphere + water pressure, *Test* 2. Total heat given up = weight of water (final − initial temp.)° F.

$$= 22{\cdot}04\ (44{\cdot}83 - 9{\cdot}49) \times \frac{9}{5}$$

$$= 22{\cdot}04 \times 35{\cdot}34 \times \frac{9}{5}$$

$$= 1402 \text{ B.T.U.}$$

In this is included heat of combustion = condensed water × 966

$$= \frac{57 \times 966}{454}$$

$$= 121 \text{ B.T.U.}$$

The heat available or given up by gas = 1402 − 121

$$= 1281 \text{ B.T.U.}$$

Now $PV = cT$

$$\therefore\ V = \frac{cT}{P} = 128{\cdot}1 \frac{\{461 + 55{\cdot}5\}}{(14{\cdot}7 \times 144 + \frac{3{\cdot}1}{12}\ 62{\cdot}5)}$$

$$= \frac{128{\cdot}1 \times 516{\cdot}5}{2115 + 16{\cdot}1}$$

$$= 31{\cdot}0 \text{ cub. ft. per lb.}$$

and Vol. used = 2·85 − ·35 cub. ft. = 2·50 cub. ft.

$$\therefore\ \text{Weight} = \frac{2{\cdot}5}{31} \text{ lb.}$$

$$= {\cdot}0807 \text{ lb.}$$

$$\text{Calorific value} = \frac{\text{Heat given up}}{\text{Weight of gas used}}$$

$$= \frac{12810000}{807}$$

$$= 16000 \text{ B.T.U. per lb.}$$

or $$\frac{16000}{31} = 516 \text{ B.T.U. per cub. ft.}$$

Test 3. Total heat given up = weight of water (final – initial temp.) ° F.

$$= 22{\cdot}04 \times (37{\cdot}35 - 9{\cdot}08) \times \frac{9}{5}$$

$$= 22{\cdot}04 \times 28{\cdot}27 \times \frac{9}{5}$$

$$= 1123 \text{ B.T.U.}$$

In this is included the heat of combustion = condensed water × 966

$$= \frac{45 \times 966}{454}$$

$$= \quad 96 \text{ B.T.U.}$$

Heat available or given up by gas $= 1123 - 96$

$$= 1027 \text{ B.T.U.}$$

Now $\quad \text{P.V.} = c\text{T},$

$$\therefore \quad \text{V} = \frac{c\text{T}}{\ } = \frac{128{\cdot}1\{461 + 55{\cdot}5\}}{14{\cdot}7 \times 144 + \frac{3{\cdot}1}{12} 62{\cdot}5}$$

$$= \frac{128{\cdot}1 \times 516{\cdot}5}{2115 + 16{\cdot}1}$$

$$= 31{\cdot}0 \text{ cub. ft. per lb.}$$

and $\quad \text{Vol. used} = 1{\cdot}87 - (-{\cdot}17) = 2{\cdot}04 \text{ cub. ft.}$

$$\therefore \text{ Weight} = \frac{2{\cdot}04 \text{ lb.}}{31}$$

$$= {\cdot}0658 \text{ lb.}$$

$$\text{Calorific value} = \frac{\text{Heat given up}}{\text{Weight of gas used}}$$

$$= \frac{10270000}{658}$$

$$= 15600 \text{ B.T.U. per lb. of gas}$$

$$\text{or } \frac{15600}{31} = 503 \text{ B.T.U. per cub. ft.}$$

Test 4. Total heat given up = weight of water (final − initial temp.) ° F.

$$= 22{\cdot}04(33{\cdot}69 - 8{\cdot}73)\,\frac{9}{5}$$

$$= 22{\cdot}04(24{\cdot}96)\,\frac{9}{5}$$

$$= 990 \text{ B.T.U.}$$

In this is included the heat of combustion = condensed water × 966

$$= \frac{40 \times 966}{454}$$

$$= 85 \text{ B.T.U.}$$

$$\therefore \text{ Heat available or given up by gas} = 990 - 85$$

$$= 905 \text{ B.T.U.}$$

Now $\quad P.V. = cT$

$$\therefore\ V = \frac{cT}{P} = 128{\cdot}1\,\frac{\{461 + 59{\cdot}5\}}{14{\cdot}7 \times 144 + \frac{3{\cdot}3}{12} \times 62{\cdot}5}$$

$$= \frac{128{\cdot}1 \times 520{\cdot}5}{2115 + 17{\cdot}2}$$

$$= 31{\cdot}40 \text{ cub. ft. per lb.}$$

$$\text{Vol. used} = {\cdot}76 - (-{\cdot}96)$$

$$= 1{\cdot}72 \text{ cub. ft.}$$

$$\therefore \text{ Weight} = \frac{1{\cdot}72}{31{\cdot}4}\text{ lb.} = {\cdot}0548 \text{ lb.}$$

$$\text{Calorific value} = \frac{\text{Heat given up}}{\text{Weight of gas used}}$$

$$= \frac{9050000}{548}$$

$$= 16500 \text{ B.T.U. per lb. of gas.}$$

$$\text{or } \frac{16500}{31{\cdot}4} = 526 \text{ B.T.U. per cub. ft.}$$

Test 5. Total heat given up = weight of water (final – initial temp.) ° F.

$$= 22{\cdot}04\ (30{\cdot}51 - 8{\cdot}90)\frac{9}{5}$$

$$= 22{\cdot}04 \times 21{\cdot}61 \times \frac{9}{5}$$

$$= 860 \text{ B.T.U.}$$

In this is included the heat of combustion = condensed water × 966

$$= \frac{35 \times 966}{454}$$

$$= 74{\cdot}5 \text{ B.T.U.}$$

Heat available or given up by gas = 860 – 74·5

$$= 785{\cdot}5 \text{ B.T.U.}$$

Now $\text{P.V.} = c\text{T}$,

$$\therefore\ \text{V} = \frac{c\text{T}}{\text{P}} = \frac{128{\cdot}1\{461 + 55{\cdot}5\}}{14{\cdot}7 \times 144 + \frac{3{\cdot}1}{12} \times 62{\cdot}5}$$

$$= \frac{128{\cdot}1 \times 516{\cdot}5}{2115 + 16{\cdot}1}$$

$$= 31{\cdot}0 \text{ cub. ft. per lb.}$$

Now vol. used = 4·42 – 2·92 = 1·50 cu. ft.

$$\therefore\ \text{Weight} = \frac{1{\cdot}5}{31} \text{ lb.}$$

$$= {\cdot}0484 \text{ lb.}$$

$$\text{Calorific value} = \frac{\text{Heat given up}}{\text{Weight of gas used}}$$

$$= \frac{7855000}{484}$$

$$= 16300 \text{ B.T.U. per lb. of gas.}$$

$$\frac{16300}{31} = 526 \text{ B.T.U. per cub. ft.}$$

Test 6. Total heat given up = weight of water (final − initial temp.) ° F.

$$= 22{\cdot}04 \times 2(25{\cdot}70 - 8{\cdot}72) \times \frac{9}{5}$$

$$= 44{\cdot}08 \times 16{\cdot}98 \times \frac{9}{5}$$

$$= 1250 \text{ B.T.U.}$$

In this is included the heat of combustion = condensed water × 966

$$= \frac{53 \times 966}{454}$$

$$= 113 \text{ B.T.U.}$$

$$\therefore \text{ Heat available or given up by gas} = 1250 - 113$$

$$= 1137 \text{ B.T.U.}$$

Now $\text{P.V.} = c\text{T}$

$$\therefore \ \text{V} = \frac{c\text{T}}{\text{P}} = \frac{128{\cdot}1\{461 + 58\}}{14{\cdot}7 \times 144 + \frac{3{\cdot}35}{12} \times 62{\cdot}5}$$

$$= \frac{128{\cdot}1 \times 519}{2115 + 17{\cdot}4}$$

$$= 31{\cdot}3 \text{ cub. ft. per lb.}$$

$$\text{Vol. used} = 2{\cdot}98 - {\cdot}65 = 2{\cdot}33 \text{ cub. ft.}$$

$$\therefore \ \text{Weight} = \frac{2{\cdot}33}{31{\cdot}3} \text{ lb.}$$

$$= {\cdot}0745 \text{ lb.}$$

$$\text{Calorific value} = \frac{\text{Heat given up}}{\text{Weight of gas used}}$$

$$= \frac{11370000}{745}$$

$$= 15300 \text{ B.T.U. per lb.}$$

$$\text{or } \frac{15300}{31{\cdot}3} = 490 \text{ B.T.U. per cub. ft.}$$

Results of all the experiments are tabulated below. They show a considerable variation in the calorific value of the gas. The experiments were run at different dates and at different times of the day, which possibly accounts for the variation in calorific value of the gas.

RESULTS OF EXPERIMENTS.

No. of Experiment . .	1	2	3	4	5	6
Weight of water used in lbs. . .	22·04	22·04	22·04	22·04	22·04	44·08
,, ,, condensed in lbs.	·134	·125	·099	·088	·077	·117
Mean temp. of inflowing water, ° C	8·71	9·49	9·08	8·73	8·90	8·72
,, ,, outflowing ,, ° C.	48·06	44·83	37·35	33·69	30·51	25·70
,, rise in temp. of water, ° C. .	39·35	35·34	28·27	24·96	21·61	16·98
,, temp. of flue gases, ° F. .	61	61·5	60	61	60	59·5
Vol. of gas used, cub. ft. . .	2·69	2·50	2·04	1·72	1·50	2·33
Weight of gas used in lbs. . .	·0859	·0807	·0658	·0548	·0484	·0745
Total heat given up . . .	1560	1402	1123	990	860	1250
Heat of combustion . . .	130	121	96	85	74·5	113
Heat given out by gas . . .	1430	1281	1027	905	785·5	1137
Calorific value of gas B.T.U. per lb.	16,700	16,000	15,600	16,500	16,300	15,300
B.T.U. per cub. ft.	534	516	503	526	526	490

APPENDIX I.—Part II.

THE DETERMINATION OF CALORIFIC VALUE OF SOLID FUELS.

Mahler Bomb Calorimeter.—This calorimeter is used to ascertain the calorific value of solid fuels. The bomb in which combustion takes place is a cylindrical vessel 4 inches in diameter and 6 inches high, made of a special metal to resist corrosion and withstand the very high pressures employed. The thickness of the metal is about 5 millimetres when oxygen is used under a pressure of 25 atmospheres. The bomb is gold-plated on the inside, to withstand the action of the nitric and sulphuric acid liberated during combustion. It is fitted with a cover screwed down by three studs and nuts, a joint of lead wire being made between the cover and body of the bomb to prevent leakage. In this cover a stuffing box is formed, through which there passes the spindle of a small valve that regulates the flow of oxygen into the bomb. There is also fastened to the inside of the cover, and suspended from it, the platinum tray which serves to hold the fuel during combustion. The height of this can be regulated by a clamping screw (see diagram). Passing through the cover, and insulated from it by a porcelain collar, is a thicker wire which is connected to one of the terminals of a battery, or accumulator cell. The bomb itself is placed in a vessel of water in which there is a very delicate thermometer graduated to tenths of a degree, and a stirrer. The latter is provided with the object of keeping the water in this inner vessel at a uniform temperature, and consists of a number of vanes connected to a vertical shaft which is caused to revolve by means of the bevel gearing on the top. The bomb stands on a metal support in which the contact surface between bomb, support, and containing vessel is as small as possible, so that no heat shall be conducted through the support,

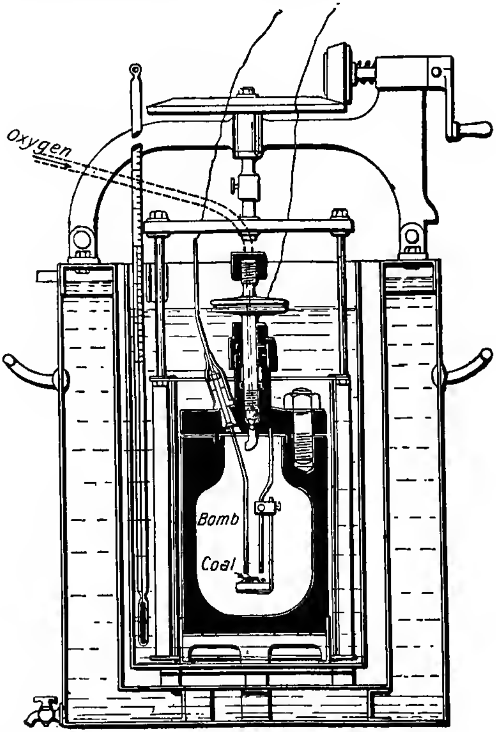

FIG. 37.—Mahler Bomb Calorimeter, showing the various parts in position.

and also to ensure that the bomb is entirely surrounded by water. The containing vessel itself is placed inside an annular receptacle which acts as a water jacket, but is separated from it, both at the sides and bottom, by means of an air space. This latter acts as a heat insulator, to keep the heat generated within the inner vessel, while the water jacket prevents leakage of heat into the calorimeter from external sources. The water jacket is usually enveloped in a layer of felt, to further insulate it from outside disturbances.

A thermometer is also placed inside the water jacket.

To obtain the calorific value of a sample of fuel, we proceed as follows:—Weigh out accurately one gramme of the powdered fuel and place it in the platinum tray. The two terminals immediately above the tray are joined by a piece of very thin iron fuse wire, which is placed so as to touch the top of the fuel. The lead wire is then put round the joint and the cover screwed on. The valve is connected to a cylinder of compressed oxygen by means of a small copper pipe and oxygen admitted *slowly* into the bomb, until the pressure gauge reads 25 atmospheres. If the oxygen is admitted rapidly, there is a risk of blowing some of the coal out of the platinum tray, and also of raising the temperature of the bomb by the sudden rise in pressure. The bomb is then placed within the calorimeter (inner vessel), which has previously been filled with a weighed quantity of water. The iron wire is now fused by connecting one of the terminals of the battery to the insulated wire, and the other to some point on the cover of the bomb. Before doing so, however, the thermometer should be read at intervals to see whether the temperature is absolutely constant, as any small error in the initial reading may introduce considerable error in the result, since the ultimate rise in temperature is quite small. The fused wire now ignites the fuel, and the temperature should be read at three-second intervals during combustion. These readings should be continued even after the temperature becomes constant, until it begins to fall, in order to make sure that the maximum temperature has actually been read. Besides the heat imparted to the water, there is some given to the calorimeter itself. The weight of water to which the calorimeter shell is equivalent may be ascertained by burning a fuel of known calorific value (*e.g.* naphthalene) in the calorimeter.

Let w = weight of fuel tested in decimals of a lb.
H = calorific value of fuel in B.T.U. per lb.

Then heat given out by fuel in combustion $= Hw$ – B.T.U.

Now let W_1 = weight of water in calorimeter in lbs.
and W_2 = water equivalent of calorimeter in lbs.
t_0 = temp. of water in calorimeter before combustion.
t_1 = ,, ,, after ,,

Then $(W_1 + W_2)(t_1 - t_0)$ = heat received by water in calorimeter. Now if there are no heat losses, and combustion is perfect, the heat given out by the fuel should equal that received by the water.

$$\therefore\ Hw = (W_1 + W_2)(t_1 - t_0)$$

$$\therefore\ H = \frac{(W_1 + W_2)(t_1 - t_0)}{w} \text{ B.T.U. per lb.}$$

Now it is clear that if H is known, as in the case of naphthalene, W_2 can easily be calculated from experiments, and, once obtained, can be used in all subsequent experiments. Then for other fuels H can be determined.

A correction should be made for the nitric acid formed in the bomb, as this is not present in ordinary combustion. The bomb should therefore be washed out, the quantity of nitric acid present determined by titration, and its heat of formation deducted from the quantity $(W_1 + W_2)\ (t_1 - t_0)$. However, some heat is actually lost by radiation from the calorimeter, so that these two errors, acting, in opposite sense, partially cancel each other. If both be neglected, the error is about ·5 per cent., so that the result is quite near enough for all practical purposes.

This type of calorimeter is better than those in which oxygen is supplied under atmospheric pressure, because, in the latter, it is very difficult, if not impossible, to make sure that all the heat of the gases is given up to the water, and that combustion is complete.

The fuel, before being used, should be dried, so that the calorific value obtained is that of dry fuel. From this, the actual heating value can be found by estimating the quantity of moisture present at any time. Thus if the calorific value of the dry fuel is 15,000 B.T.U. per lb., and we have 2 per cent. of moisture present, the actual heat present per lb. of coal is 15,000 × ·98, or 14,700 B.T.U. per lb.

To make the working out of results on the Mahler bomb clearer let us take an actual example :—

Weight of coal in platinum tray . . 1 gramme.
Weight of water in calorimeter . . 2000 grammes.
Heat equivalent of calorimeter . . 580 „

∴ Total equivalent weight of water = 2580 „
Initial temperature of water = 17·3° C.
Final temperature of water = 20·1° C.
Rise in temperature due to combustion = 2·8° C.
∴ Heat given out by 1 gramme of coal = 2580 × 2·8.
= 7230 calories.
∴ Higher calorific value of coal = 7230 cals. per gm.
or 13,000 B.T.U. per pound.

From this, the lower value may be obtained by deducting the latent heat of the water formed during combustion, and by estimating the weight of moisture present in the coal itself if the sample has been dried.

Other calorimeters for solid fuel are the William Thomson calorimeter and the Fischer calorimeter. In the former the fuel is burnt under ordinary pressure in an atmosphere of oxygen. The fuel is burnt in a platinum crucible. A glass combustion chamber fits over the crucible, and into it oxygen is passed by means of a tube. The combustion chamber is immersed in a glass vessel. It may be added that the results obtained with this type of apparatus are not very reliable, as the fuel is burnt in an imperfect manner, and a certain amount of carbon monoxide is formed. This remark also applies to the Fischer calorimeter.

APPENDIX II.

Gas Analysis.—In any gas-producing plant it is important to know the chemical composition of the gas produced, and, to ascertain this, it must be analysed. It is necessary, therefore, first of all to get a sample of the gas that is being generated. For this purpose a sampling tube is often used. This consists of a large wide tube of some 120 cub. cm. capacity, narrowed down at each end, and closed by means of two cocks. This is first filled with water. One end is then attached by means of rubber tubing to the gas main (or a bye-pass from it), while the other cock is opened and the water run out, the vacuum thus formed drawing the gas into the sampling tube. When the water has *nearly* all run out, both cocks are closed, thus imprisoning about 110 c.c. of the gas, ready for analysis. A better method is to use a small gas holder in which the gas is imprisoned over mercury. If an average sample of the gas extending over some hours is required, a much larger aspirator must be used. This may consist of a glass bottle with an opening in the top connected to the gas main, and another at the bottom from which the water is run off. The time over which the sampling extends may be varied by adjusting the rate at which this water is run off. The gas may then be transferred from the bottle or sampling tube to the gas holder by running in water at one opening and connecting the other to the holder, when the water drives out the gas, which may then be collected under pressure. The gas is then passed into the burette, which consists of a graduated measuring tube and a pressure tube. These are connected at the bottom by a rubber tube, and are filled up to a certain point with mercury. The measuring tube is closed at the top by a cock. Now when it is desired to fill the measuring tube with gas, the pressure tube is first raised so that the mercury completely fills the measuring tube, and the cock closed. The top of the measuring tube is then connected by a rubber tube to the gas holder, in which is the sample of gas. The pressure tube is then lowered, so that the top of the mercury column in it is much lower than that in the measuring tube. Thus, as soon as the cock at the top of the latter is opened, the mercury runs down that tube in order to make the level at the two tubes equal, and, in doing so, draws the gas over from the holder. When sufficient gas has been drawn over, the cock of the measuring tube is closed, and the volume of the gas at atmospheric pressure observed by reading the volume in that tube when the level of the mercury in the two tubes is the same. The various gases present are then absorbed by different reagents contained in gas pipettes, a separate pipette being used for each reagent. Fig. 38 shows the apparatus.

The pipette itself consists of two or four bulbs at different levels, connected by bent tubes. The top of the measuring tube is connected by means of a rubber tube and pinchcock to the capillary tube of U-form which forms the entrance to the pipette. A strip of white glass or porcelain is fixed at the back of this tube to render the position of the liquid within it more visible. This tube is connected to a bulb of about 150 c.c. capacity, which is nearly filled with the absorbing reagent. The bulb is connected by means of a U-tube with another of the same size, but placed a little higher up, so that the lower bulb may be flooded if desired. The reagent therefore nearly fills the lower bulb, completely fills the U-tube, and occupies a small part of the upper bulb. The gas is now passed into the pipette by opening the pinchcock of the measuring tube and raising the pressure tube so that the mercury rises in the measuring tube and drives the gas before it into the first bulb of the pipette, where it meets the reagent. Let us suppose that we wish to absorb the CO_2 present in the gas. The reagent in the pipette is then potassium hydrate (KHO). The gas is passed into the first bulb, as we have seen, until the mercury from the measuring tube begins to rise up the capillary U-tube, when the pinchcock is closed. This ensures

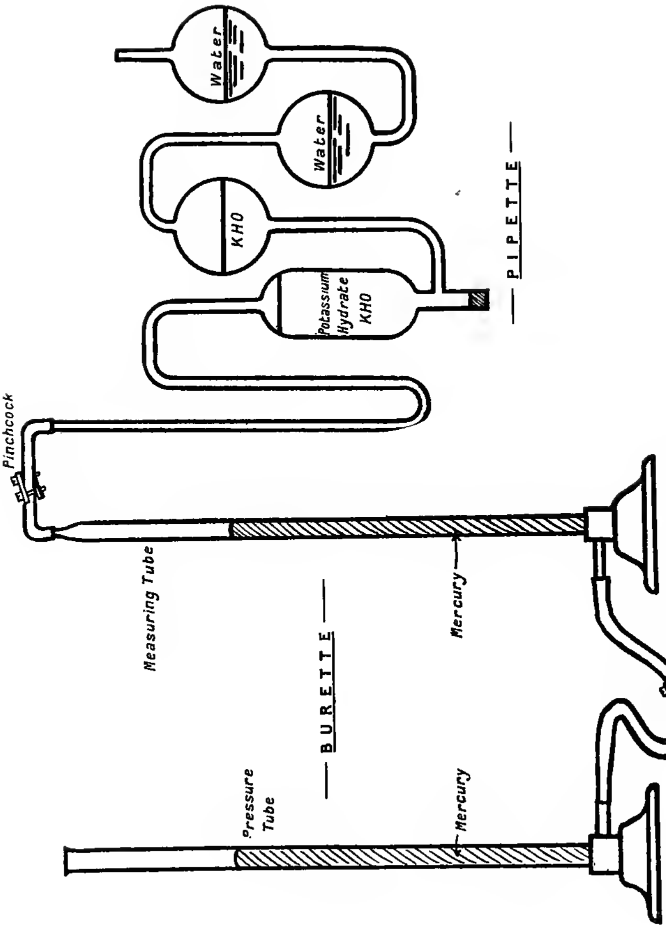

FIG. 38.—Apparatus used for Analysis of Producer Gas.

that all the gas is in the bulb, and consequently in contact with the KHO. The gas is left in contact with the absorbent for five minutes, the pipette being shaken from time to time so that all the gas shall come thoroughly into contact with the reagent. At the end of that time the pressure tube is lowered so that all the gas is drawn back into the burette. When the reagent begins to rise up the capillary tube, the pinchcock is shut. The volume of the gas at atmospheric pressure is again observed, the diminution in volume being the amount of CO_2 absorbed. The absorption of carbon monoxide is performed by a solution of cuprous chloride (Cu_2Cl_2). As it is important that this solution should not come into contact with the air, the pipette now has two extra bulbs which contain water to seal up that end of the pipette which is farthest from the burette. For the first absorption, the gas is passed over an old solution of Cu_2Cl_2 for about 15 minutes. To make sure that the whole of the CO is absorbed, the gas is then passed over a new solution of Cu_2Cl_2 which has not before been used. After this has been done for 10 minutes, the gas is passed back into the burette and its volume at atmospheric pressure observed. The diminution gives the volume of CO present in the original volume of gas.

The oxygen in the gas is now absorbed by alkaline pyrogallol in a double pipette, and the residue consists of hydrogen, methane, (CH_4) and nitrogen.

Some of the gas is now passed out of the burette, about 30 c.c. being allowed to remain. To this is added about 30 c.c. of air. The mixture is passed into an explosion pipette, which consists of a bulb with stopcocks and two platinum wires sealed into the glass. Sparks are passed between these points by means of an electric battery and induction coil. When passed back into the burette, a diminution in volume will be found to have taken place. This is due to the combination of the hydrogen with oxygen and of the methane with oxygen, forming water and carbon dioxide. The CO_2 thus formed is found by absorption in KHO in the manner already explained. But CH_4 forms its own volume of CO_2. Therefore in this way the volume of CH_4 present in the original gas may be found. Now methane forms, on combustion, twice its volume of water. Therefore a contraction equal to twice the volume of methane in the gas was due to the methane itself. The remaining contraction after combustion was due to the hydrogen in the gas. This hydrogen is thus equal to two-thirds of the contraction just found. The volume of nitrogen in the gas is the difference between the original volume and the sum of all the other gases found. To fix our ideas, let us take a concrete example.

The following volumes are observed :—

	cub. cms.
Volume of gas in burette at start	100
,, after absorption by KHO	93·5
,, ,, ,, Cu_2Cl_2 (old)	78
,, ,, ,, Cu_2Cl_2 (new)	69·5
Volume of gas after absorption by alkaline pyrogallol	69
Volume of gas before explosion	30
,, after addition of air	60
,, ,, explosion	44
,, ,, absorption by KHO	42·5

CO_2 :

Diminution in volume after absorption by KHO = 6·5 cc.

∴ Since original volume of gas was 100 cc.,

Percentage of CO_2 present = 6·5.

CO :

Diminution in volume after absorption by old Cu_2Cl_2 = 15·5 cc.

,, ,, ,, new Cu_2Cl_2 = 8·5 cc.

∴ Total diminution in volume due to absorption of CO = 24 cc.

∴ CO in gas, by volume = 24 per cent.

O_2 :

Diminution in volume after absorption by alkaline pyrogallol = ·5 cc.

∴ Oxygen in gas = ·5 per cent.

CH_4 :

39 cc. of gas were run out and 30 cc. air added.

Diminution in vol. on explosion = 16 cc.

,, ,, after absorption by KHO = 1·5 cc.

∴ Vol. of CH_4 present = 1·5 cc., since the vol. of CH_4 present = vol. of CO_2 formed.

$\therefore$ Vol. of CH_4 in original gas $= 1{\cdot}5 \times \frac{69}{30} = 3{\cdot}5$ per cent.

H_2:

Vol. of steam formed by $CH_4 = 2 \times 1{\cdot}5 = 3$ cc.

$\therefore$ " " hydrogen $= 16 - 3 = 13$ cc.

$\therefore$ Vol. of hydrogen present in 30 cc. gas $= \frac{2}{3} \times 13 = 8{\cdot}68$ cc.

$\therefore$ Vol. of hydrogen in original gas $= 8{\cdot}68 \times \frac{69}{30} = 20$ per cent.

$\therefore$ Composition of gas by vol. was—

$CO_2 = 6{\cdot}5$ per cent. $CO = 24{\cdot}0$ per cent. $O_2 = {\cdot}5$ per cent.
$CH_4 = 3{\cdot}5$ per cent. $H_2 = 20{\cdot}0$ per cent. $N_2 = 45{\cdot}5$ per cent.

This analysis is also useful in providing a check on the calorific value of the gas as obtained by the Junker calorimeter. As we have seen, for all gases we have the relation

$$PV = KT,$$

where P is pressure in lbs. per sq. ft. V = vol. in cub. ft.
T = absolute temperature. K = constant.

The values of K are

For methane $K = 96{\cdot}4$. For hydrogen $K = 770{\cdot}26$.
For carbon monoxide $K = 55{\cdot}15$.

Now these are the only heat-giving gases present.

Let us take hydrogen first:—

One lb. of hydrogen on burning to water gives out 62,032 B.T.U.

From the above relation

$$\text{Vol. per lb. of hydrogen} = \frac{770{\cdot}26 \times 493}{144 \times 14{\cdot}7}$$

$= 180$ cub. ft. at 32° F. and 14·7 lbs. per sq. in.

$\therefore$ 1 cub. ft. of hydrogen gives out $\frac{62032}{180} = 344{\cdot}5$ B.T.U.

Now 1 cub. ft. of hydrogen weighs $\frac{1}{180}$ lb.

And 1 lb. of hydrogen gives 9 lbs. of water.

$\therefore$ 1 cub. ft. of hydrogen yields $\frac{9}{180}$ or $\frac{1}{20}$ lb. of water.

$\therefore$ The latent heat of the water so formed $= \frac{966}{20}$ or 48·3 B.T.U.

Since in practical work the water is all rejected as steam, this latent heat is not utilised, and so must be deducted from the 344·5 B.T.U. just found (called the higher calorific value).

The lower calorific value for hydrogen is, then, $344{\cdot}5 - 48{\cdot}3 = 296{\cdot}2$ B.T.U. per cub. ft.

Now for the carbon monoxide :—

1 lb. of carbon as CO burning to CO_2 yields 10100 B.T.U.

Volume per lb of $CO = \frac{55{\cdot}15 \times 493}{144 \times 14{\cdot}7} = 12{\cdot}85$ cub. ft. at 32° F. and 14·7 lbs. per sq. in.

$\therefore$ 1 lb. of CO burning to CO_2 gives out $\frac{12}{28} \times 10100$ B.T.U. = 4330 B.T.U.

$\therefore$ 1 cub. ft. of CO burning to CO_2 gives out $\frac{4330}{12{\cdot}85} = 337$ B.T.U.

Methane.

1 cub. ft. of CH_4 weighs $\frac{8}{180} = {\cdot}0445$ lb.

1 lb. of CH_4 contains $\frac{3}{4}$ lb. of carbon and $\frac{1}{4}$ lb. of hydrogen.

$\therefore$ Higher calorific value per lb. of $CH_4 = \frac{3}{4} \times 14500 + \frac{1}{4} \times 62032 = 26383$ B.T.U.

$\therefore$ At 32° F. and 14·7 lbs. per sq. in., the higher calorific value of methane $= 26383 \times {\cdot}0445 = 1170$ B.T.U. per cub. ft.

For every lb. of CH_4 we get $\frac{9}{4}$ lbs. of water formed.

$\therefore$ 1 cub. ft. of CH_4 gives $\frac{1}{10}$ lb. of water.

$\therefore$ Latent heat of water to be deducted $= 96{\cdot}6$ B.T.U. per cub. ft. of gas.

$\therefore$ Lower calorific value of methane $= 1170 - 96{\cdot}6 = 1080$ B T.U. per cub. ft.

This value is a little too high, as some heat is absorbed in the molecular changes required to break up CH_4 into carbon and hydrogen. We therefore take the higher value as 1050 and the lower as 953 B.T.U.

Taking the same example of gas that we analysed above, we will find out its calorific value.

Heat given out by Combustion of one cub. ft. of Producer Gas.

In each cub. ft. of gas we have ·2 cub. ft. of hydrogen.

$\therefore$ The combustion of this hydrogen is responsible for ${\cdot}2 \times 344{\cdot}5 = 69$ B.T.U. (higher value).

The lower value would then be ·2 × 296·2 = 59·3 B.T.U.

The carbon monoxide gives out ·24 × 337 = 81 B.T.U.

The methane is responsible for ·035 × 1050 = 36·8 B.T.U. (higher value), or ·035 × 953 = 33·4 B.T.U. (lower value).

Thus the higher calorific value of 1 cub. ft. of this gas is

$$69 + 81 + 36{\cdot}8 = 186{\cdot}8 \text{ B.T.U.},$$

and the lower value is 59·3 + 81 + 33·4 = 173·7 B.T.U.

In this way, therefore, the calorific values obtained by the Junker calorimeter can be checked from the analysis of the gas.

APPENDIX III.

The Destruction of Tar in the Gas Producer.[1]—During the lectures a correspondent made inquiries concerning the above problem. It was, of course, impossible to go fully into the matter at that time, but it is considered probable that the following notes may be of general assistance to readers who wish to follow the matter up. There is no doubt that the use of bituminous coal is a problem which needs to be gone into very thoroughly, and that when it can be satisfactorily accomplished in suction gas producers the price of production will probably be lower. The subject of destruction of tar is here treated in quite a general way. The opinion contained is considered to be the latest available. Since the introduction of bituminous fuels in producer plants for internal combustion engines, the purification of the gas has become a very important matter.

Apart from its cheapness and wide occurrence, bituminous coal possesses other advantages over anthracite and coke. It contains gaseous hydrocarbons whose calorific value amounts to about 20 per cent. of the total calorific value of the coal.

These hydrocarbons possess a high calorific value per cubic foot, and thus enable a large quantity of heat to be carried in a comparatively small bulk, resulting in a considerable economy in the gas production.

The quantity of tar in bituminous coal frequently amounts to 4 or 5 per cent., and may even be as high as 15 per cent. of the coal. The producer gas made from such a coal must be purified of this tar before use in the internal combustion engine. The destruction of the tar can be effected in two ways. The first method consists of the complete combustion of the tar in the presence of air, the resulting carbon dioxide and water vapour being reduced by passing them over red-hot coke. This method, it is true, completely destroys the tar, but it is not efficient in other respects, since the volatile gases of the coal are burnt with the tar.

---

[1] See *Engineering*, Jan. 31 and Feb. 7, 1905, from which the illustrations of this section have been reproduced, by the permission of the Editor.

The second method, although not so complete in its destruction of the tar, preserves these volatile gases, and consequently yields a richer producer gas. It consists of the decomposition of the tar at a high temperature. The tarry vapours are split up into, first, such gases as marsh gas, ethylene, etc., carbon monoxide and hydrogen; and secondly, into heavy hydrocarbons and carbon, the hydrocarbons being burnt with the tar, and the carbon being deposited on the coke. A large number of producers have been constructed, which more or less efficiently bear out the above considerations, but, owing to limited space, it will be only possible to describe very generally a few of the more recent.

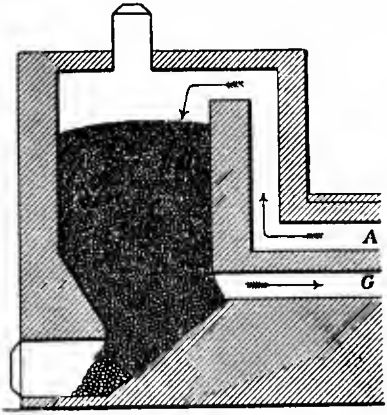

Fig. 39.—Pintsch, 1882.

Perhaps the simplest type of producer is that known as the inverted combustion type. Here, contrary to the usual custom, the air passes down through the fresh fuel to the zone of combustion, where any tarry vapours it may carry are destroyed.

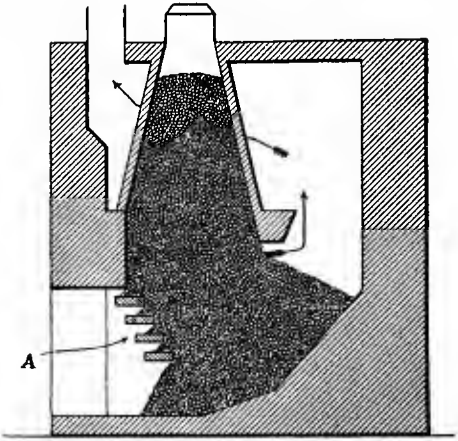

FIG. 40.—C. Siemens, 1864.

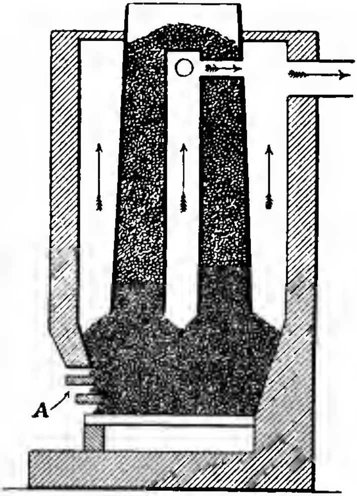

FIG. 41.—Krupp, 1881.

A similar method is adopted in the Thwaite patent of 1904, except that here there is an additional air supply below the top of the fuel.

In this type of producer, as the air passes down through the fuel, the zone of combustion must necessarily be somewhat narrow, and consequently the amount of volatile substance distilled from the fuel cannot be very great. It can be increased, however, by heating the incoming air. This is carried out by a regenerative principle in the Pütoch Producer.

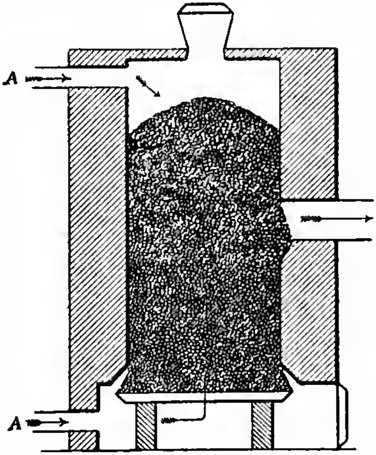

Fig. 42.—Dowson, 1902.

C. Siemens in 1864, Moller in 1878, and Krupp in 1881, patented producers in which the hot gases pass round the retort before leaving the generator, thus giving up a considerable part of their heat to the fuel. This distils the volatile substances, which are driven out by the pressure of formation. As a high temperature and considerable time are required for complete distillation, it is probable that only the lighter hydrocarbons are driven off, the tarry products being decomposed in the lower part of the generator.

A considerable number of producers have been invented in which the air enters at the top and bottom of the fuel, the gas outlet being halfway up the generator. Such a producer has the advantage over the single inverted type in that the combustion zone is enlarged, extending from the lower air inlet to the gas outlet. As the distillates would burn near the outlet, reduction, however, would probably be incomplete. Many producers have been constructed, differing in detail, but in the main similar in design, in which the distillates are drawn off by suction, burnt in a side chamber, and then forced upwards to the gas outlet through the hot fuel, where they are reduced. The suction is obtained in a variety of ways. In Olschewsky's patent of 1881 it is obtained by an air blast injector; Fr. Siemens employs a similar blast, while Whitfield, Hovine, Brenille, and others use a steam jet. In Genty's producer of 1901 the desired effect is obtained by a fan.

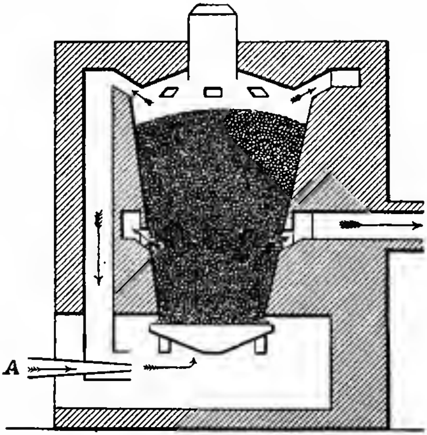

FIG. 43.—Olschewsky, 1881.

So far, producers of one chamber only have been dealt with, but there are many producers containing two or more chambers, thus allowing the distillation and destruction of the tarry matter to be entirely separated. In some of these producers the coke obtained from the distillation of the bituminous fuel is used for the reduction of the tar, while in others a separate supply of coke is employed.

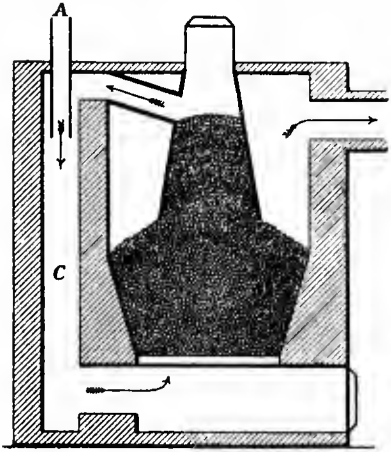

FIG. 44.—Fr. Siemens, 1893.

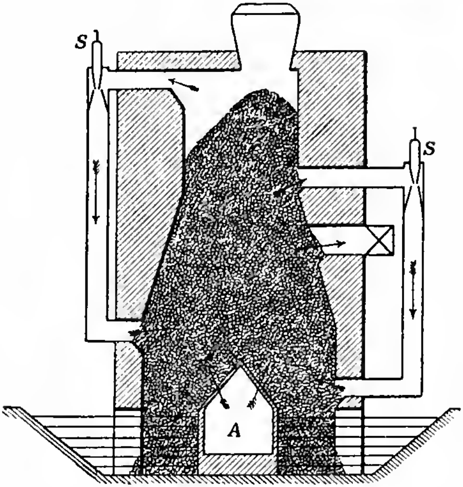

FIG. 45.—Whitfield, 1902.

These producers may be divided into two classes, those in which air is admitted to both chambers, where the tar is respectively being distilled and destroyed, and those in which air is admitted to the distillation chamber only. In the former class the tar will be destroyed by more or less complete com-

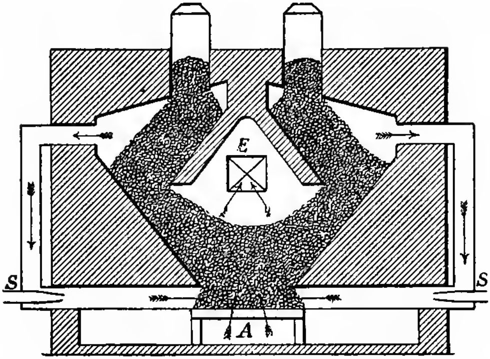

Fig. 46.—Hovine and Breuille, 1903.

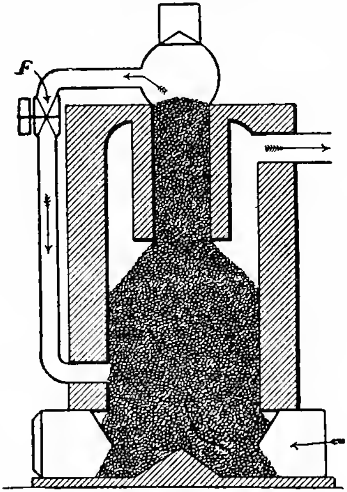

Fig. 47.—Genty, 1901.

bustion, while in the latter the destruction will take place by decomposition.

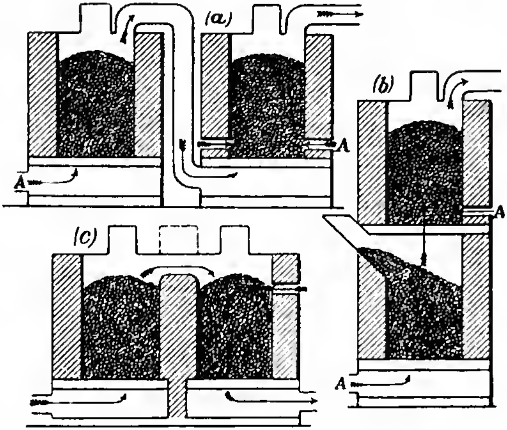

FIG. 48.—Gasmotorenfabrik Deutz, 1900.

Dealing first with the class in which the tar is destroyed by combustion, the producers of Olschewsky, Fr. Siemens, the Deutz Company, Jahns, and Boutillier and Riché, are examples of this type.

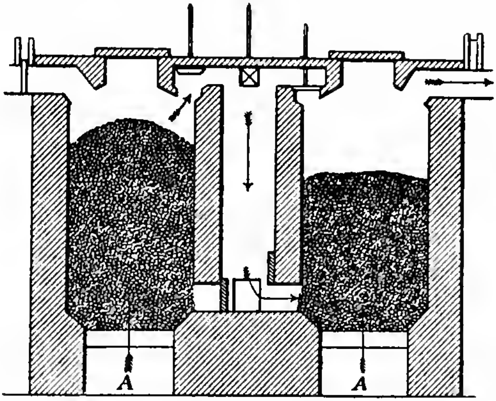

FIG. 49.—Jahns, 1903.

An explanation of the Riché producer will explain in a general way the method of working of all such producers. Air passes through the bituminous fuel in the first chamber through the grate, and the gases thus formed are burnt by means of the secondary supply of air A. They then pass on through the coke in the second chamber, where they are reduced.

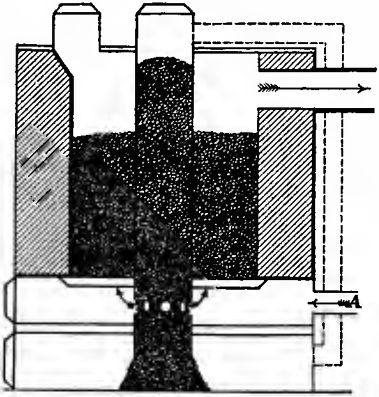

Fig. 50.—Boutillier, 1904.

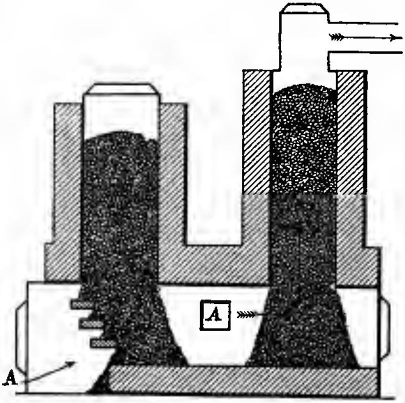

Fig. 51.—Riché, 1902.

The second class, of which Rowe's, Sutherland's, and Bell's producers are examples, have no secondary supply of air, or the air supply is so reduced that decomposition only of the tar can take place. In the Rowe producer the outer chamber contains the bituminous coal, while the central retort contains coke. The distillates formed in the upper part of the outer chamber are decomposed in the central retort.

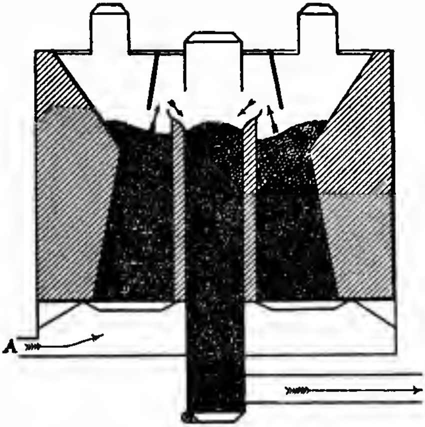

Fig. 52.—Rowe, 1903.

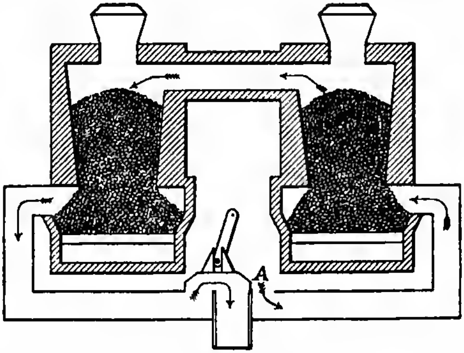

Fig. 53.—Sutherland, 1882.

Sutherland's producer consists of two chambers, which are used alternately for gas production and tar decomposition. Bell employs three chambers, connected together in series. By an arrangement of valves the order of the chambers can be varied so that the chamber which has previously been heated up by combustion is employed for the decomposition of the tar. For the decomposition of the tar to be satisfactorily carried out, the layer of coke must be of considerable depth, and hence those producers which most nearly carry out those conditions would probably give the best results.

Those producers which depend for their action on the driving force of a jet of steam are not suitable for use with very bituminous coal, as the reduction of the steam lowers the temperature too far to allow of reduction of the gases unless a large quantity of air be used, which would naturally impoverish the gas.

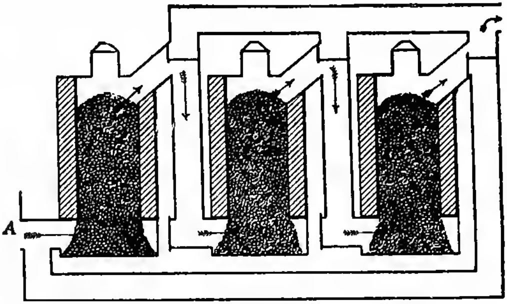

FIG. 54.—Bell, 1905.

It has often been said that a poor gas is more suitable for gas engine work, as danger of pre-ignition is reduced. This is only partly true. A gas rich in hydrogen is very liable to pre-ignite, but when the gas is enriched with hydrocarbons this danger is not only obviated, but a very suitable gas for the internal combustion engine with a high flame temperature is obtained.

Hence, from this aspect, the method of destruction of tar by decomposition, although not so complete as that by combustion, seems much more preferable, as the hydrocarbons of the coal are not only retained in the power gas, but their quantity increased by the decomposition of the tar.

APPENDIX IV.

METHOD OF DETECTING THE PRESENCE OF CARBON MONOXIDE IN GAS ENGINE EXHAUST.

As the efficiency of a gas engine depends largely on the explosive mixture, it is a very important matter to obtain the correct proportion of air.

If carbon monoxide be present in the exhaust, it is a sure proof that complete combustion has not been realised, and, consequently, that the air supply is insufficient.

Mr R. E. Mathot, during the discussion on a recent paper, described a simple yet very effective method of detecting the presence of carbon monoxide in the exhaust.

A small flask, about 2 ins. in diameter and 4 ins. high, is chosen and fitted with a cork, through which pass two tubes, one of which dips into about 1 inch of mercury contained in the bottom of the flask. This latter tube B is connected with the exhaust, so that at each stroke exhaust gases will be blown into the flask. The

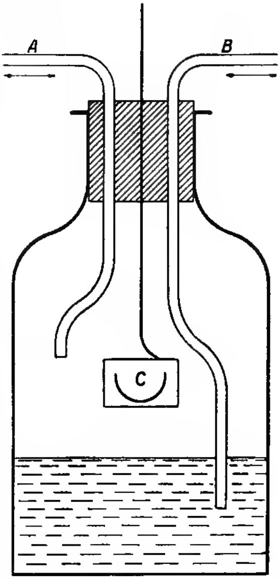

Fig. 55.—Apparatus to determine if more than 1 per cent. CO is in exhaust gas.

mercury acts as a check valve to prevent the withdrawal again of the gases on the suction stroke. The presence of carbon monoxide is detected by means of a piece of blotting-paper dipped five or six times in a solution of double chloride of palladium and sodium, of such strength as to give a dark brown colour. The blotting-paper is dried after each immersion, and finally hung within the flask.

If more than 1 per cent. of carbon monoxide be present, the paper will lose its brown colour and become grey.

Carbon-Monoxide Poisoning.—The above test is made to determine whether the combustion in the engine cylinder is complete. It must be understood that the presence of carbon monoxide is dangerous to human health and life. Dr J. S. Haldane has made a very complete study of the toxic action of this gas, and gives the following data. When 0·05 CO is present, a man will feel giddiness on exertion after from half an hour to two hours. With 0·1 CO present, after the same period, he will be unable to walk. With 0·2 CO present, the man will, after the above period, lose consciousness and may finally expire. With 0·4 CO present there will be, after two hours at the most, probable death. With 1·0 CO a man will, after a few minutes, lose consciousness, and will, before long, expire. The treatment for CO poisoning is to apply artificial respiration at once, and oxygen should be supplied to the patient from a cylinder of the gas, and the supply continued for at least ten minutes. The patient should be kept lying down and warm. Of course, the exhaust from gas engines is led away from confined spaces.

APPENDIX V.

A NOTE ON CAPITAL COST OF SUCTION GAS PLANTS AND ENGINES.

On p. 126 is published a table of the prices of gas engines and suction gas plants for the ordinary type of horizontal engines. Information on the matter of the price of vertical engines having been requested at the close of the lectures, the following tables are given, and have been compiled from figures supplied by Messrs Newton Bros. A section of the producer made by this firm is shown in fig. 13, p. 32, and their ingenious water regulator is shown on p. 27 (fig. 11). The regulator is of simple construction. A small canvas diaphragm, open to the suction of the engine, rises and falls in sympathy with charging strokes of the piston. This lifts a brass tube having parts which cover and uncover other parts, thus automatically regulating steam supply in proportion to load on the engine. There are no valves or close fitting parts. This firm claim to have made the first successful suction producer at work in this country, and it was erected in 1901 at Derby. The following figures will serve as a guide, especially to the student, who is apt to be unaware of commercial costs. Other makers will supply at about the same figures, but it is always advisable to compare specifications as well as actual capital costs. One firm may reduce the weight of the brasses, another may not use balance weights, and so on.

[Tables.

PRICE LIST OF SUCTION GAS PRODUCERS.

B.H.P. Capacity of Plant.	Price of Suction Gas Plant complete. £	Approximate Net Weight in cwts.
10	84	25
15	94	28
20	110	35
25	112	36
30	125	40
35	127	45
40	130	50
45	145	55
50	160	65
60	170	70
70	185	85
80	195	90
90	225	92
100	240	105
110	255	115
120	265	120
130	275	125
140	290	135
150	310	140
180	355	160
210	395	180
240	440	200
280	490	230
320	550	265

These prices are for suction gas plants complete with all accessories, iron ladder, charging bucket, stoking tools, etc., but do not include coke for the scrubber. For sizes above 150 H.P. this firm recommend power-driven fans in place of hand fan, for making gas to start. For shipping weight, add 5 per cent. to net weights.

These figures will, it is hoped, give the reader, and especially the engineering student, some idea of the cost of suction gas plants. It must be remembered that cost will be involved for foundations, erection, etc.

PRICE LIST OF VERTICAL ENGINES.

Brake Horse-power on Suction Gas.		Speed, Maximum R.P.M.	Price of Engines only. £	Price of Water Tanks. £	Approximate Net Weight of Engine only. In Cwts.
10		250	96	4	46
15		250	135	6	65
20		250	160	9	75
25		250	190	9	87
30	Made two cylinder if desired, but prices 10% higher, and speed would be 230 R.P.M.	250	210	11	93
35		230	240	14	115
40		220	275	15	130
45		210	310	20	160
50		210	340	25	200
60		210	395	30	220
70		210	460	35	235
80	Two cylinder.	220	540	40	260
90		210	600	43	290
100		210	650	45	320
120		210	700	Special prices to suit varying conditions.	360
140		210	760		400
150	Three cylinder.	210	950		445
180		210	1015		485
210		210	1225		530
240	Four cylinder.	210	1435		575
280		210	1710		620

PRICE LIST OF HORIZONTAL ENGINES.

Brake Horse-power on Producer Gas.	Speed, Maximum R.P.M.	Price of Engines only. £	Price of Water Tanks. £	Approximate Net Weight of Engine only. In Cwts.
5	300	63	3	
6	280	78	3	26
8	250	92	4	37
12	250	110	6	45
14	250	131	6	54
21	250	152	9	62
30	250	180	11	84
35	230	230	14	100
40	220	260	15	120
45	210	315	20	133
50	210	346	25	180
60	210	378	30	200
75	210	475	35	250
90	200	560	43	370
100	200	605	45	285
120	180	700	Special prices to suit varying conditions.	360
150	180	920		450
170	180	1030		475
200	200	1210		...
260	180	1515		...
300	170	2050		...

All of these engines are fitted with specially heavy fly-wheels, balanced cranks, and special governor to ensure steady running. No pulleys are included in the prices, but these may be fitted—prices varying according to size. All engines are fitted with magneto-electric ignition, and above 50 H.P. they are arranged for compressed air-starting—prices for compressors on application. The engines will develop the above powers on constant load for *continuous* runs. For shipping weight add 10 per cent. to above net weights.

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